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# Production of Low-Sulphur Tailings by Hydrocycloning

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## ABSTRACT

Acid mine drainage (AMD) is an environmental problem in gold mines containing sulphur minerals. The potential for acid drainage in tailings facilities must be considered when studying their dry closure. Therefore, controlling the sulphur content in the final layer of tailings deposition has the potential to prevent AMD after closure. In this context, the rougher flotation tailings were hydrocycloning in a pilot plant in a gold mining company to assess the potential for generating modified tailings with low-sulphur content. A total of 10 samples were composited over one hour of pilot plant operation. The hydrocyclone overflow showed an average reduction of 36.2% in sulphur content and an average metallurgical recovery of 20.0%. The underflow had an average increase in sulphur content of 16.8% and 80.0% metallurgical recovery. These results demonstrated the possibility of generating modified tailings with reduced sulphur content through hydrocycloning.

**Keywords:** Hydrocycloning; Low-sulphur tailings; Acid Mining Drainage (AMD).

## INTRODUCTION

Gold (Au) is the chemical element with a high melting point of 1,063°C, low hardness, and a specific mass of 19.3 g/cm³ (BRANCO, 2008). Throughout history, gold has been a highly valued metal, primarily used as a raw material for producing jewellery and ornamental objects due to its chemical inertness and malleability (HOUGH & BUTT, 2009). This metal can be found in its native form, combined with silver to form an alloy known as Electrum, in the form of minerals known as gold tellurides, or associated with sulphur minerals, where fine particles of gold are present within sulphur grains (MARSDEN & HOUSE, 2006; MENDES, 1999).

The presence of sulphur minerals in oxidizing environments at gold mines can lead to the occurrence of Acid Mine Drainage (AMD), a phenomenon caused by the oxidation of these minerals when they come into contact with water and atmospheric oxygen. This phenomenon is characterized by low pH, high concentrations of dissolved metals, and high concentrations of sulphates (DE MELLO *et al.*, 2014). Acid drainage can occur in tailings piles, tailings facilities, heap leach piles, stockpiles, and open pit mine (BORMA & SOARES, 2002).

The mineral pyrite is one of the main contributors to acid drainage; however, other iron sulphides such as pyrrhotite, arsenopyrite, and chalcopyrite can also generate acidic solutions. The acidity produced due to the oxidation of these sulphides depends on the nature of the metal and its capacity to hydrolyse (DE MELLO *et al.*, 2014). Table 1 presents the chemical formula, specific mass, and products resulting from the complete oxidation of these primary acid drainage-generating sulphides.

**Table 1 -** Chemical formula, specific mass, and main products resulting from the complete oxidation of the major acid-generating sulphides ores.

| Sulphur Mineral | Chemical formula | Specific mass$^2$ (g/cm³) | Aqueous species after complete oxidation$^3$ |
|---|---|---|---|
| Arsenopyrite | $AsFeS$ | 6,07 | $Fe^{3+}, SO_4^{2-}, H^+, AsO_4^{3-}$ |
| Chalcopyrite | $CuFeS_2$ | 4,10 - 4,30 | $Fe^{3+}, SO_4^{2-}, H^+, Cu^{2+}$ |
| Pyrite | $FeS_2$ | 5,00 - 5,02 | $Fe^{3+}, SO_4^{2-}, H^+$ |
| Pyrrhotite | $Fe_{1-x}S$ | 4,58 - 4,65 | $Fe^{3+}, SO_4^{2-}, H^+$ |

Sources: $^{1,2}$ web mineral; $^3$ adapted from Hutchison & Ellison (1992).

The tailings resulting from gravity concentration and flotation processes can generate acid mine drainage (AMD) if disposed improperly in tailings facilities. Since water, oxygen, and sulphurs are the primary reagents that need to be in contact simultaneously for acid drainage generation, an effective strategy for preventing acid generation is to restrict the contact between one or more of these reagents (BOIS *et al*., 2004). Therefore, maintaining water cover during tailings facility operation can prevent acid drainage by limiting the availability of oxygen, because the maximum concentration of dissolved oxygen in natural waters is about 25,000 times lower than in the atmosphere (DE MELLO *et al*., 2014). However, during dry closure, it is essential to implement complex covers to control oxygen flux and minimize water flow. These covers act as protective barriers to mitigate substantial acid drainage (BORMA & SOARES, 2002).

In addition to using these covers to limit acid drainage, studies have shown the potential of using modified tailings as part of the closure layers. Bussière *et al.* (2004) evaluated the use of low-sulphur tailings resulting from desulfurization through flotation as a moisture-retaining layer in covers with capillary barrier effects (CCBE). Leaching column tests demonstrated that this cover system was able to reduce oxygen flux and consume a fraction of the oxygen passing through before reaching the sulphur tailings. Furthermore, Bussière *et al.* (2004) achieved more than a 99% reduction in the release of zinc, copper, and iron in the percolated water when comparing column tests with and without this cover system. On the other hand, Dodchuk *et al.* (2013) assessed the effectiveness of a single layer of low-sulphur tailings used in the closure of Detour Lake Mine Tailings Facility in Ontario, Canada. They demonstrated through modelling that, although the layer was coarser than the unmodified tailings, it was able to reduce oxygen flux by up to 50%, however, this reduction could drop to 5% if this layer was finer than the unmodified tailings. Thus, reducing the presence of sulphide minerals and controlling the particle size of the final tailings deposition layer becomes an alternative of protection against acid drainage after dry closure.

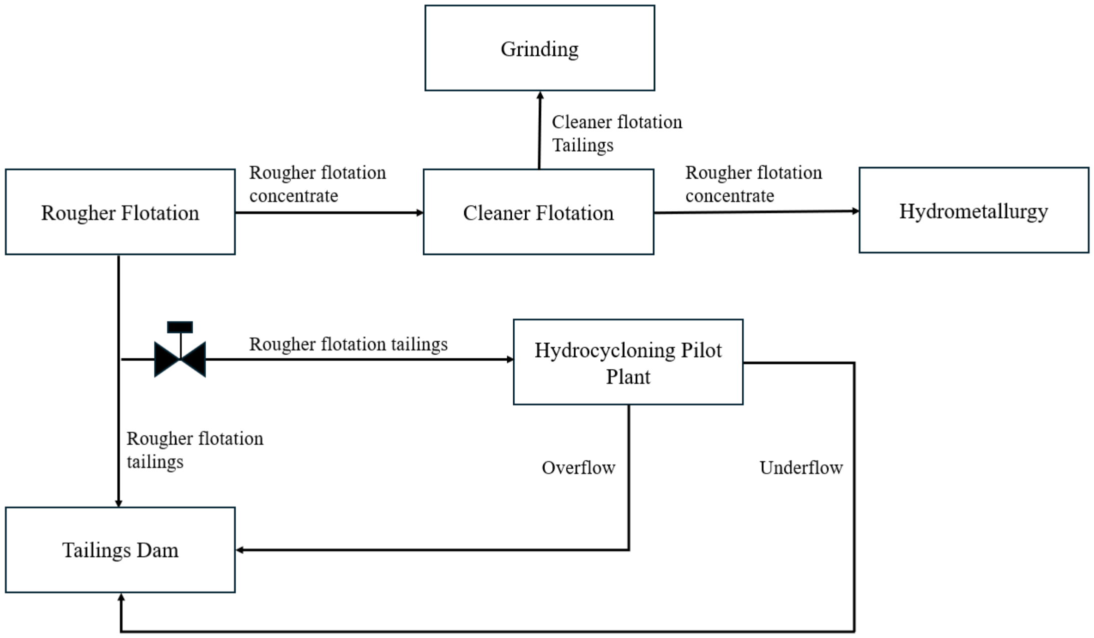
The main sulphides minerals present in the flotation tailings of the gold mining under study are pyrite, pyrrhotite, and arsenopyrite, minerals with the potential to generate acid drainage. In this context, the present study seeks to examine the impact of hydrocycloning sulphide tailings on the distribution of sulphur between underflow and overflow streams. This approach is considered as an alternative for reducing sulphur content in the final tailings layer deposited in tailings facility, aiming to prevent the generation of acidic effluents after closure.

## MATERIALS AND METHODS

Hydrocycloning tests of the rougher flotation tailings were carried out at the pilot hydrocycloning plant of the gold mining under study. A bypass was installed on the tailings pipeline from the rougher flotation to the tailings facility. When the manual valve of this bypass was opened, the tailings were directed by gravity to the hydrocycloning plant, which contained one GMAX26 hydrocyclone from FLSmidth with vortex and apex dimensions of 14.0 cm (5.5") and 11.4 cm (4.5"), respectively. The feed pressure was regulated by adjusting the valve and was maintained at 1 bar (14.5 psi). Both the overflow and underflow streams were directed to the facility. A total of ten samples were taken from the hydrocyclone feed, overflow, and underflow.

Sampling was taken between March and May 2024. The percentage of solids, mass recovery, sulphur metallurgical recovery, and particle size distribution of each stream were determined. The samples were composited over one hour of plant operation, with approximately 1 L of material collected every 10 minutes, resulting in a total of about 6 L of tailings from each stream. Figure 1 illustrates the test setup of this pilot hydrocycloning plant.

**Figure 1** –Operational diagram for the hydrocycloning pilot plant



In order to determine the percentage of solids in the streams, the total mass collected was weighed. Subsequently, the samples were vacuum-filtered and dried in an oven at a temperature between 150°C and 180°C for about 4 hours. Based on the percentage of solids results for each stream, the mass recovery of the underflow and overflow was calculated using Equations 1 and 2, respectively.

$$Q_{UF} = \frac{UF\ (A - OF)}{A(UF - OF)} * 100 \qquad \text{Equation 1}$$

$$Q_{OF} = \frac{OF\ (A - UF)}{A(OF - UF)} * 100 \qquad \text{Equation 2}$$

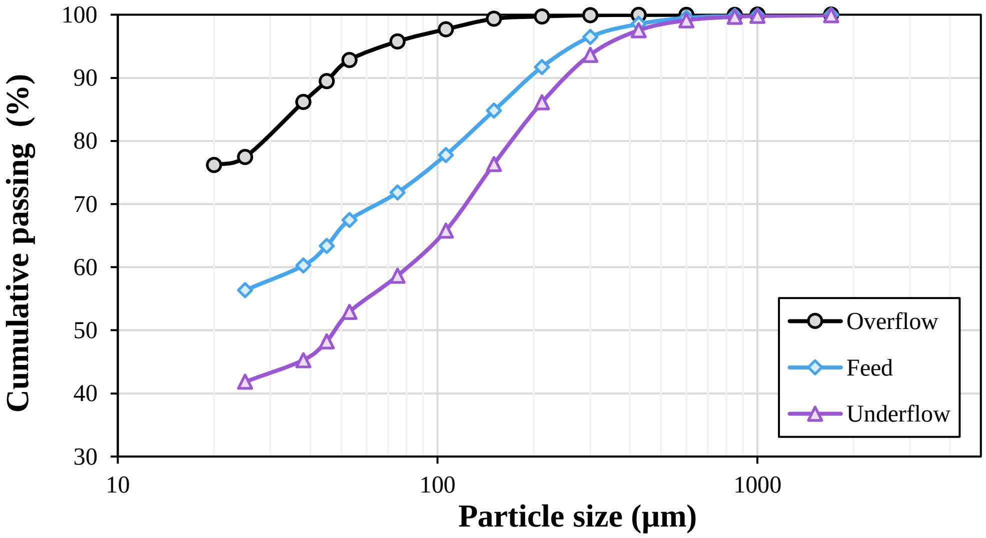
Where: A - Percentage of solids in the feed, UF - Percentage of solids in the underflow, and OF - Percentage of solids in the overflow.

The dry samples were then split using a rotary sample splitter. Two aliquots were prepared: one for sulphur content determination and the other for particle size distribution by dry screening for 15 minutes. The sulphur content was determined by high-temperature combustion sulphur analysis with non-dispersive infrared (NDIR) detection, using SC832 model from LECO.

## RESULTS AND DISCUSSIONS

The comparative average particle size distribution of the experimental results is shown in Figure 2.

**Figure 2** - Comparative average particle size distribution curve of the experimental results of feed, overflow, and underflow.



The P80 particle sizes for the feed, underflow, and overflow are 120 µm, 173 µm, and 28.8 µm, respectively. Compared to the unmodified tailings, the overflow material is significantly finer. This finer material, when used as a cover layer, enhances moisture retention, and reduces oxygen flux, as shown in the model study by Dodchuk *et al.* (2013).

The results of mass recovery and metallurgical sulphur recovery are shown in Figures 3 and 4, respectively.

**Figure 3** - Mass recovery of the ten hydrocyclone tests and the average results

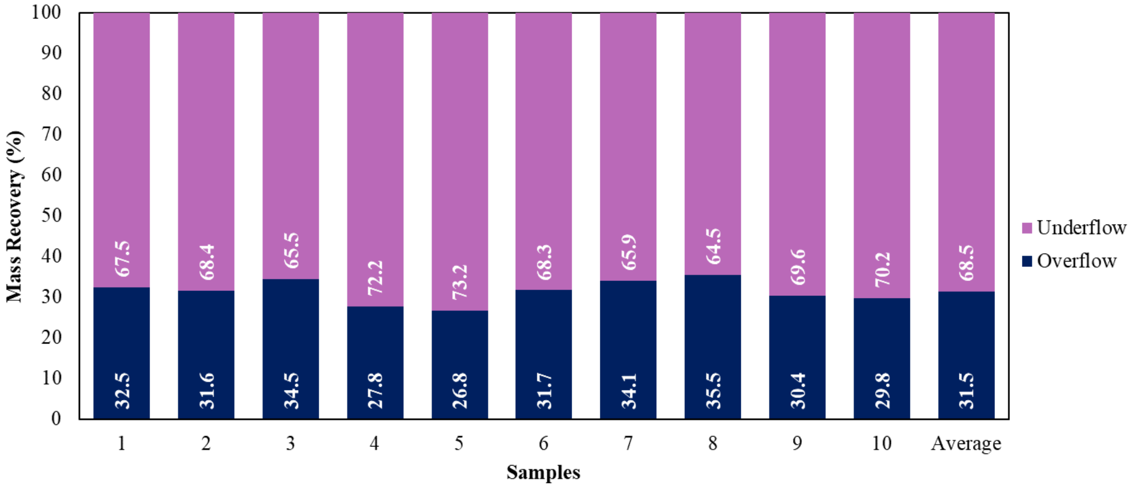
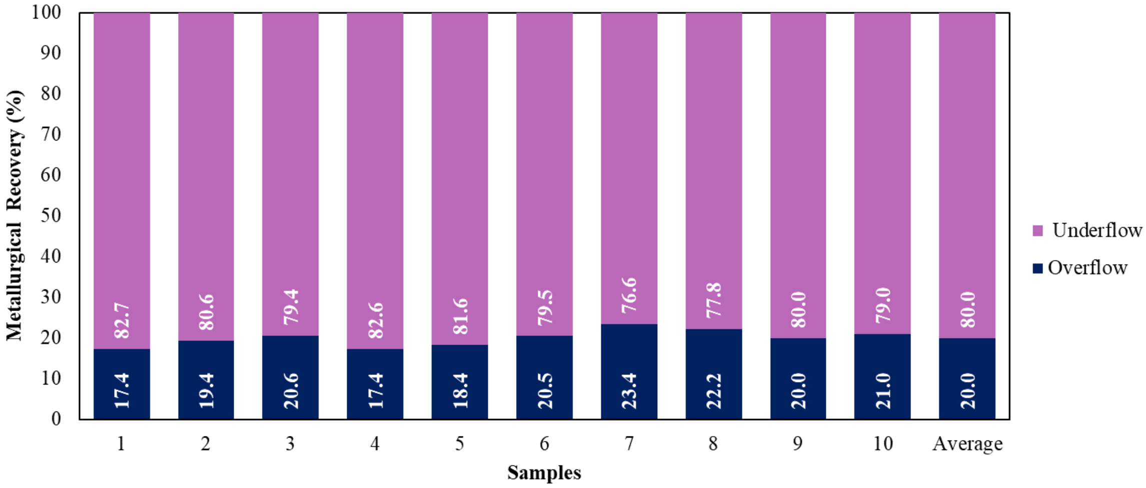


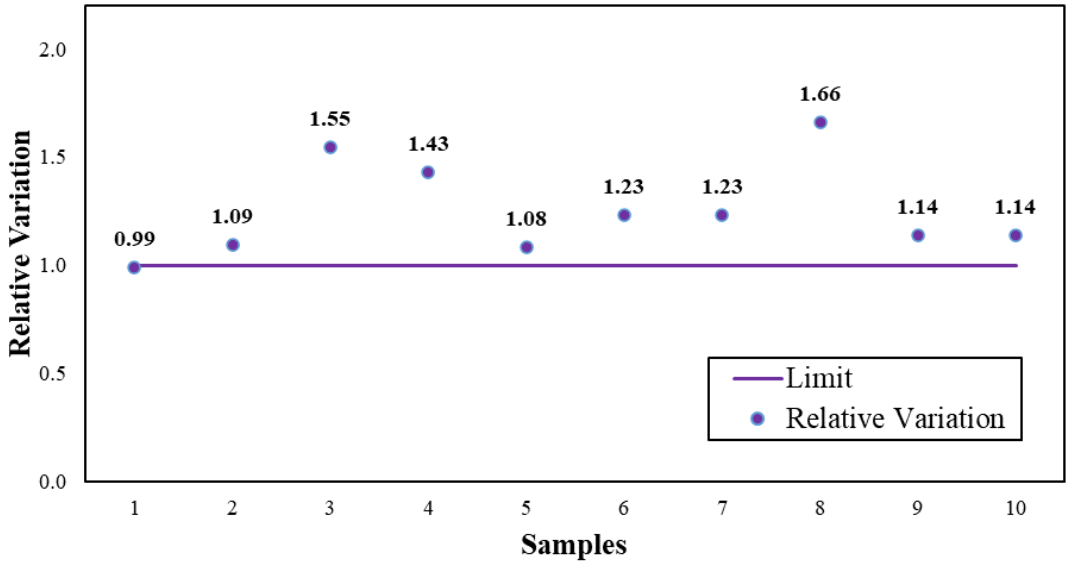
**Figure 4** - Metallurgical recovery of the ten hydrocyclone tests and the average result



The data show that sulphur recovery remained stable and above 80% on average in the underflow, significantly reducing the amount of this element in the overflow. This phenomenon occurs because the hydrocyclone principle of operation, which is based on centrifugal force. The hydrocyclone is fed with tailings at high pressure, and a downward rotational movement is produced due to the equipment's configuration. Larger and denser particles are forced towards the hydrocyclone’ s walls by the stronger centrifugal force, while smaller particles are pushed toward the centre. At the apex, only the coarser and denser particles exit, forming the underflow. In the lower outlet, a constriction creates an internal vortex that directs finer and lighter particles to the upper outlet, resulting in the overflow. The sulphur minerals pyrite, arsenopyrite, and pyrrhotite are over 1.6 times denser than the in-situ ore, which has a specific mass of 2.81 g/cm³ (data provided by the gold mining company), and therefore tend to concentrate in the underflow. More information about the operation of the hydrocyclone can be found in CETEM (2018).

The relative variation of sulphur content in the feed is presented in comparison to the absolute sulphur content set as the reduction target to achieve in the test. The average sulphur content in the feed is 1.25 times higher than this target. The data is presented in the graph in Figure 5.

**Figure 5 -** Relative variation in feed sulphur content compared to the reduction target set for the test.



The same comparison is done for underflow and overflow as can be seen in the graphs in Figures 6 and 7, respectively. The average sulphur content in the overflow is 0.80 times the reduction target and in the underflow is 1.47.

**Figure 6 -** Relative variation in the overflow sulphur content compared to the reduction target set for the test.

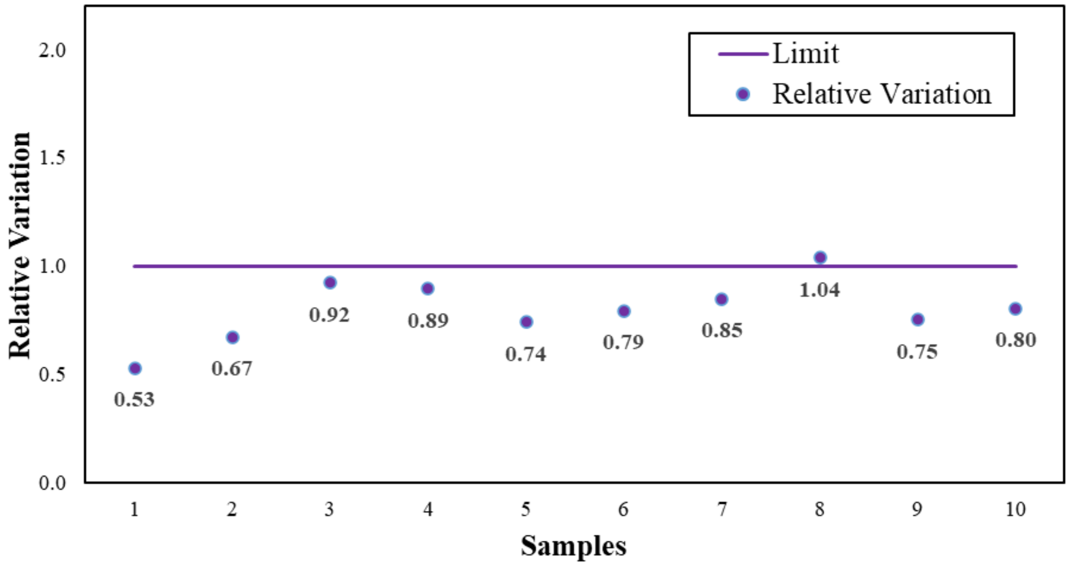


**Figure 7 -** Relative variation in the underflow sulphur content compared to the reduction target set for the test.

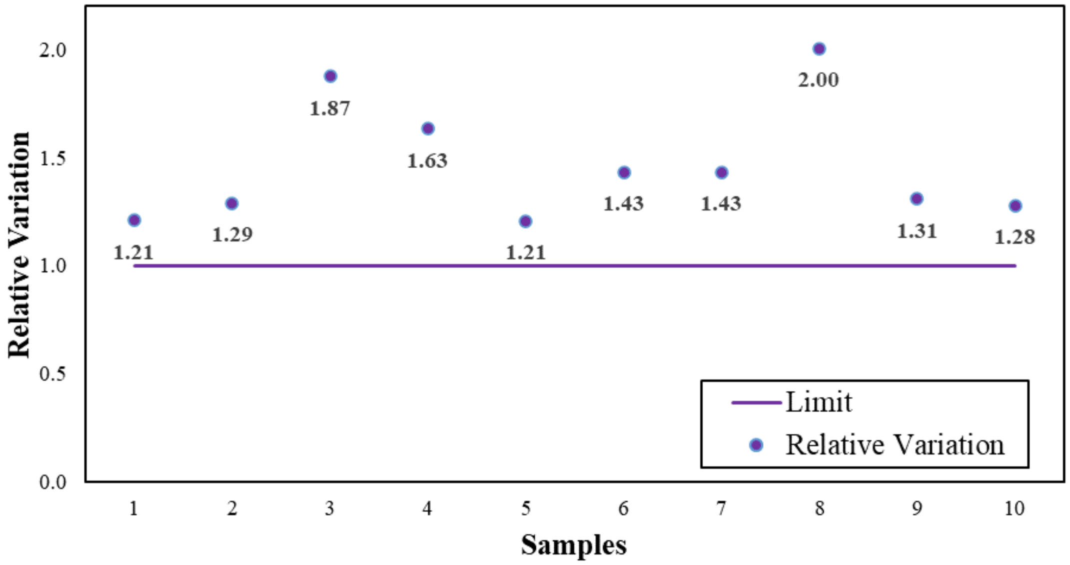


Table 2 shows the percentage relative variation of sulphur content in the overflow and underflow compared to the absolute sulphur content in the feed.

**Table 2 –** Variation in sulphur content in the overflow and underflow relative to the absolute sulphur content in the feed.

| **Sample** | **Overflow** Reduction in sulphur content relative to the feed (%) | **Underflow** Increase in sulphur content relative to the feed (%) |
|---|---|---|
| 1 | 46.6 | 22.4 |
| 2 | 38.5 | 17.8 |
| 3 | 40.3 | 21.3 |
| 4 | 37.4 | 14.4 |
| 5 | 31.4 | 11.5 |
| 6 | 35.4 | 16.5 |
| 7 | 31.2 | 16.1 |
| 8 | 37.5 | 20.6 |
| 9 | 34.1 | 14.9 |
| 10 | 29.3 | 12.4 |
| **Average** | **36.2** | **16.8** |

The average sulphur content in the overflow was reduced by 36.2%, bringing it below the reduction target set for the test, except for the sample 8. Thus, when the feed sulphur content was 1.66 times higher, it was not possible to reduce the overflow content below the target, considering the operational parameters and the hydrocyclone configuration.

Additionally, it is observed that 68.5% of the solids are directed to the underflow. This limits the availability of material in the overflow and prolongs the time needed to form the layer. The underflow, on the other hand, exhibits an average sulphur content increase of 16.8%. This material can be strategically deposited in the deeper areas of the facility or redirected to new deposition structures such as tailings facilities and mine pits. Alternatives for processing this material, including desulfurization, should also be considered (DE CARVALHO *et al.*, 2023).

Acid Neutralising Capacity (ANC) and Maximum Potential Acidity (MPA) analyses were not conducted to assess the acid potential ratio (ANC/MPA). These tests should be performed in future sampling to identify changes in this ratio compared to the results from the unmodified tailings. According to the mining company, tailings

ANC/MPA is maintained above 1.5, thus remaining within the uncertainty zone regarding acid generation potential as defined by Hutchison & Ellison (1992).

## CONCLUSION

The results from the pilot hydrocyclone test indicated that sulphur can be effectively concentrated in the underflow, achieving 80% metallurgical recovery of this element, while reducing its concentration in the overflow. An average sulphur content reduction of 36.2% was observed in the overflow, whereas the sulphur content in the underflow increased by 16.8%. However, when the feed sulphur content was 1.66 times higher than the test limit, the sulphur content in the overflow did not decrease below this limit. This highlights the process's limitations based on the feed content and the hydrocyclone configuration. The overflow P80 showed a significant reduction compared to the unmodified tailings. Thus, considering the obtained results, the overflow can be deposited to form the final tailings layer with low sulphur content, aiming reduce oxygen flux and the sulphur availability in the material that comes into contact with other closure layers.

Further studies should be conducted to evaluate the potential of this modified tailings layer to limit the occurrence of AMD after closure. In this context, the suggested supplementary studies include carrying out a leaching column tests with this low-sulphur tailings as part of the cover layer system. Additionally, simulating sulphur metallurgical recovery considering the mineralogical composition of the ore to predict the recovery of this element by varying the operational parameters and hydrocyclone configuration. Finally, analysing the behaviour of hydrocyclone overflow and underflow when deposited in the facility, considering their rheological characteristics, deposition angle, and consolidation over time.

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