Centinela, challenges in the concentration of complex ores

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Minera Centinela, Chile

1. Introduction

Antofagasta Minerals S.A. (AMSA) has been operating since 2001 in the Centinela Mining District, in the Second Region of Chile. Copper production capacity in the form of copper cathodes was around 100 ktf/y, which comes from minerals oxidized through a leaching process, solvent extraction and exploited by Minera El Tesoro (MET). At the end of 2010, the Esperanza Project came into operation, whose processing capacity for copper sulfide minerals, with significant gold and molybdenum content, was around 97 kt/d. In 2014 AMSA decided to unite both operations, oxides and sulfides, forming Minera Centinela.

In the case of the sulfide line, since the beginning of operation there has been a growth in the processing of the Concentrator Plant from the original project of 97 ktpd, passing through the design capacity assurance project and finally the implementation of the Comminution Fallback project (July 2021). Processing capacity of 105 ktpd was achieved in 2021 increasing to approximately 107 ktpd scheduled for 2023, according to the company's current Base Case (CB2021).

Minera Centinela, for its sulfide process, is a low-grade copper deposit, which has a complex gangue and also a high variability in pyrite content. These ore characteristics represent a constant challenge, as they affect the performance of the flotation stage (metallurgical recovery and concentrate grade).

In addition to the above, a new sulfide mineral pit has recently commenced operation and projects focused on achieving higher levels of processing in the concentrator plant have been successfully implemented. Essentially, this will imply addressing new challenges to achieve optimal results in the metallurgical indicators of the flotation stage.

2. Characteristics Mineral Feed Plant

The ore projected within CB2021 has fed Cu grades ranging between approximately 0.45% and 0.55% for the first 15 years of the LOM. With regard to Mo, on average, the grade is around 100 ppm, and from the year 2025 an increase is scheduled reaching values above 150 ppm. The tendency of Cu, Mo, Au and Ag for the duration of the project is presented in the following figure.

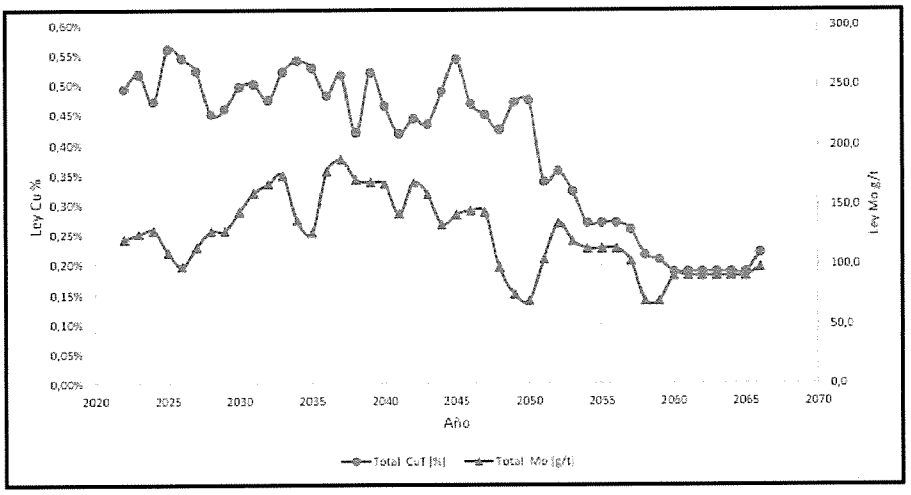

Figure 1: Cu/Mo feed grade Base Case 2021.

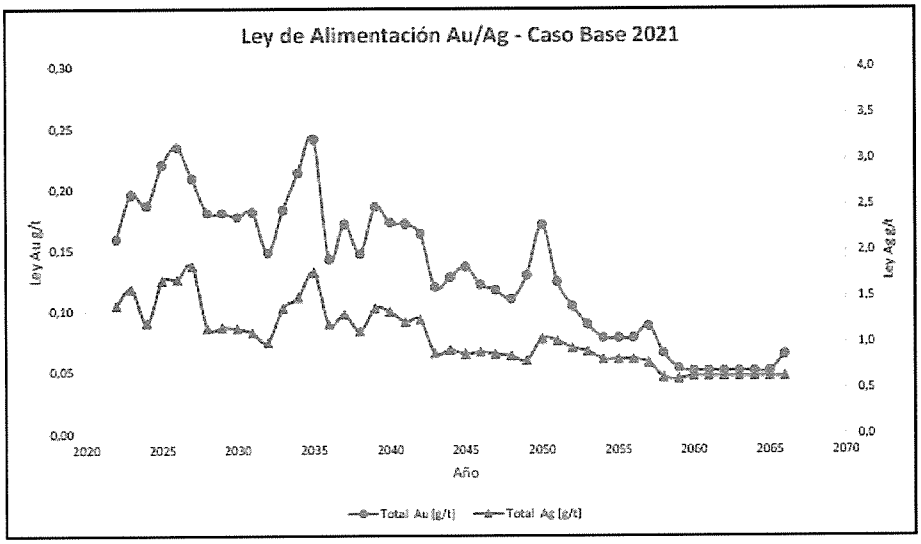

Figure 2: Au/Ag feed grade Base Case 2021.

Geometallurgical units have been defined in relation to the floatability of the different minerals, the most complex being those related to Resource 1 and 2.

Resource 1: Recovery and low concentrate grade

Resource 2: Recovery and mean concentrate grade

Resource 3: Recovery and high concentrate grade

Figure 3 shows the distribution of the resources for flotation considered in the CB2021.

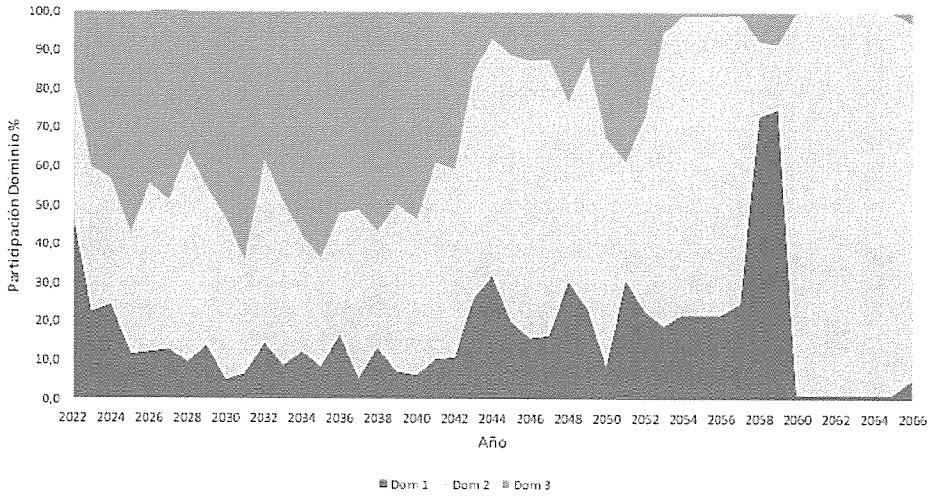

Figure 3: CB2021 Flotation Resource Distribution.

3. Flotation Optimization Projects

The implementation of the Comminution Fallback project considers the transfer of mineral from the 2nd/3rd stage crushing plant to the SAG mill, generating an average annual treatment of 105 ktpd, equivalent to an instantaneous treatment of around 113 ktpd. The volumetric load inside the grinding circuit under this condition has direct impacts on the collective flotation circuit:

- Lower Rougher recovery due to higher P80 and shorter residence time.
- Loss of recovery due to selectivity of the rougher stage due to the inability of the circuit to treat higher flows in the cleaning stage and reach the target final concentrate grades.

Figure 4 shows the flow diagram of the Comminution Fallback Project.

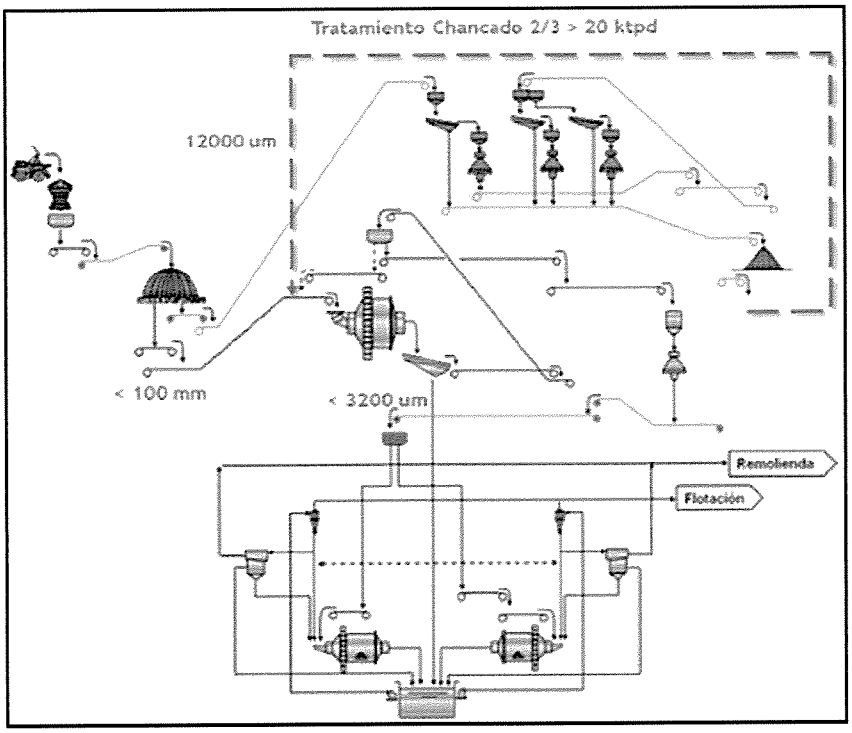

Figure 4: Comminution Fallback Project.

These impacts give rise to the "Flotation Fallback Project" that seeks to implement alternatives to make the collective flotation circuit more flexible, for the handling of complex materials, which are mainly expected between 2022-2031. This is when considering the majority of the mineral is from resources 1 and 2, the processing of low-grade sulfide stocks, as well as to adsorb the treatments projected with the implementation of the Comminution Fallback Project at the MCEN Concentrator Plant. In this way, the Flotation Fallback project seeks to achieve the following:

- Increase global recovery, as a result of the release of flow rate restrictions in the flotation circuit.
- Increase the Cu grade of the collective concentrate
- Provide operational continuity to the Mo plant due to an increase in the Mo grade in the collective concentrate

In summary, the Flotation Fallback project consists of the incorporation of a new cleaning stage in the Collective Flotation circuit and the improvement of the hydraulic capacity for the transport of intermediate flows that allow it to operate under conditions of greater treatment. Figure 5 presents the flowsheet of the Flotation Fallback project.

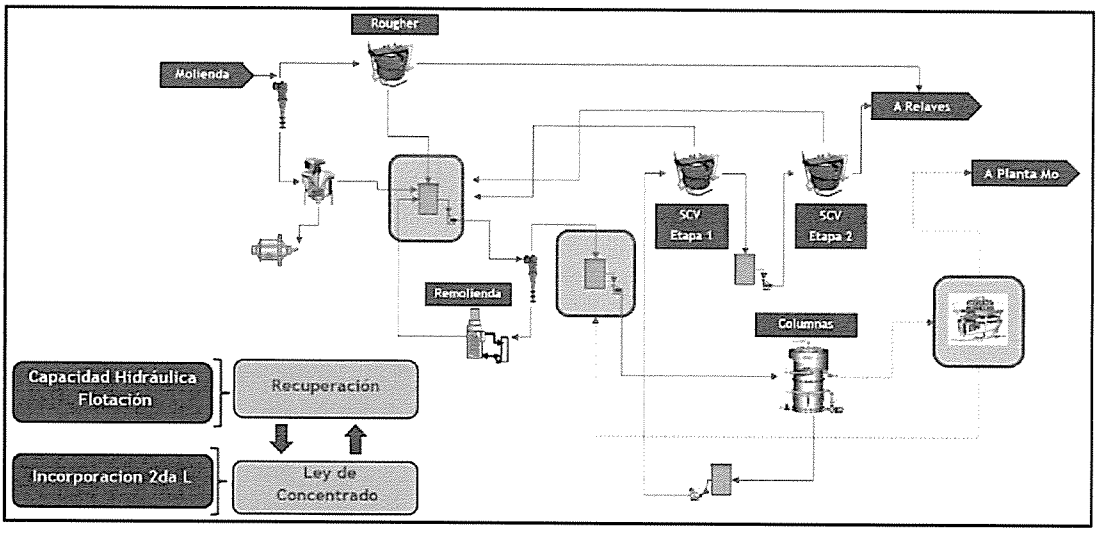

Figure 5: Collective Flotation Fallback Flowsheet.

The study strategy for the Flotation Fallback project was as follows:

1) Test at an industrial scale with 100% low-grade sulfides and sampling for metallurgical tests

2) Technical evaluation, metallurgical characterization and laboratory and pilot tests of alternative technologies (columns, Jameson Cells, conventional flotation cells)

3) Tradeoff of these alternative technologies

4) Engineering Development, Procurement and Construction

For the selection of the technology to be implemented as a second cleaning stage, flotation cells such as columns, conventional and pneumatic cells were considered. To determine this, Centinela commissioned a tradeoff study to support the decision to implement the project. This tradeoff study considered the evaluation of flotation technology focused on metallurgical results, number of main and auxiliary equipment, footprint, Capex and Opex.

According to the results of the tradeoff study, the Jameson Cells alternative obtained the best results, since they do not require forced aeration, it has a lower footprint (approximately 50% less compared to columns) and presents lower Capex and Opex in relation to the other alternatives evaluated.

In metallurgical terms, the Jameson cell has better performance, validated through laboratory and pilot tests and industry references.

Jameson cell flotation technology is not new to Minera Centinela. In fact, laboratory and pilot tests were carried out in 2014 and 2018, in different flows of the collective flotation plant. In all these tests, the high selectivity of this technology could be observed.

In 2014, laboratory tests were carried out with Jameson technology in scavenger tailings flow. The result indicated high selectivity, achieving Cu contents of 8% in concentrates, from feeds of the order of 0.2% Cu.

In 2018, pilot tests were carried out at Centinela with rougher concentrate feeds, first stage cleaner and scavenger tailings feeds. In all tests, high enrichments were achieved, reaching final concentrate qualities (> 20% Cu) in rougher concentrate flows (2 - 4% Cu) and in first stage cleaner feed (1.5-2.5% Cu). In the case of the scavenger tail, laboratory results from 2014 were validated, reaching concentrate grades of 9% Cu.

4. Experimental Evaluation Flotation Technologies

In the month of April 2021, an industrial test was carried out for 2 days with ore from low-grade stock (SSBL), corresponding to ore with the worst metallurgical performance that the Esperanza pit has and corresponds to 100% Resource 1 flotation. From this test, collective Cu-Mo concentrate samples were obtained to evaluate technological alternatives through laboratory and pilot tests with the aim of obtaining higher concentrate grades. The tests were carried out by SGS between April and May 2021.

Table 1 presents the chemical characterization of the collective concentrate sample tested. It should be noted that given the characteristics of this sample (low Cu content and high gangue content), the concentration process is considered complex.

Table 1: Characterization of the sample.

Sample	Cu (%)	Fe (%)	Mo (%)	Au (g/t)	Ins (%)	P80 (microns)
Concentrate 100% SSBL	10.6	24.5	0.37	3.2	27.7	36

Figure 6 shows the distribution of Cu, Mo and INS (insolubles) elements by size. It is observed that the elements of interest (Cu and Mo) are mostly found in the -400# fraction, that is, with a size less than 37 µm. The latter suggests that the technology to be selected must have good recovery performance for these size fractions.

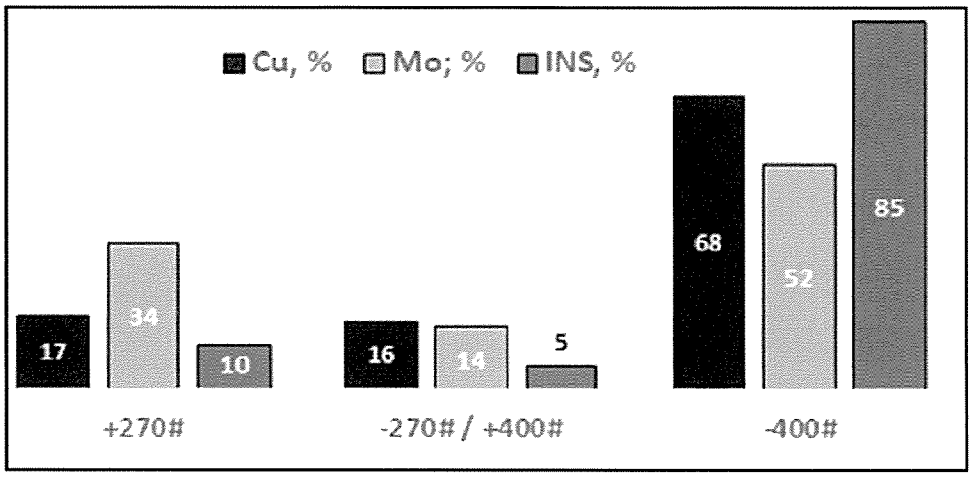

Figure 6: Distribution by sizes of Cu, Mo and Insoluble in the sample to be tested.

5. Laboratory Scale Evaluation

Two laboratory tests were carried out with the concentrate sample generated with SBL stock in the industrial plant. A conventional kinetic test was carried out, where the indicators of recovery and concentrate grade are evaluated in an exhaustion test over time, to be used for sizing columns and mechanical cells and a dilution test for Jameson-type pneumatic cell technology. This test consists of the successive flotation of concentrates generated from a standard flotation stage. Figure 7 shows the results obtained from both laboratory tests.

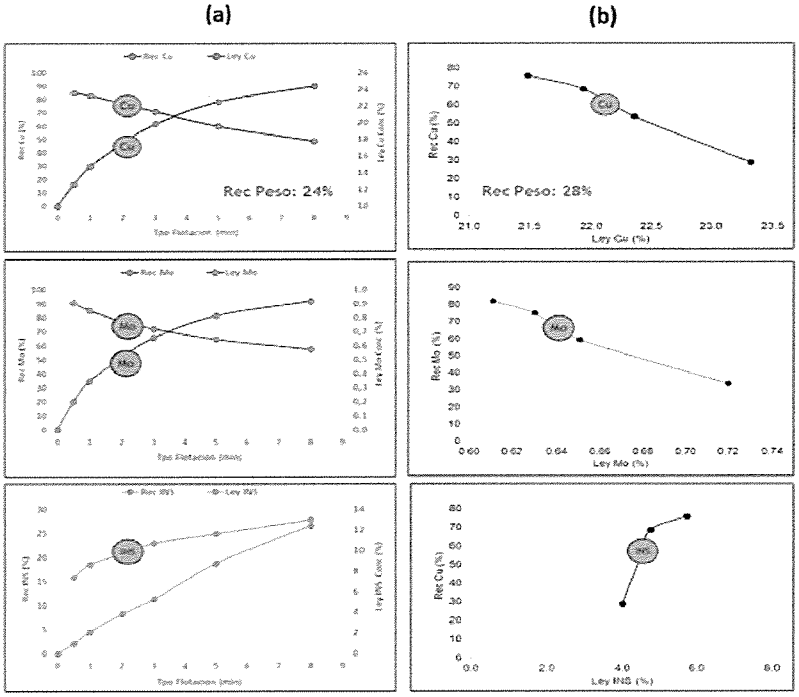

Figure 7: Results of laboratory tests (a) Conventional Kinetics and (b) Dilution Test.

For the case of Cu, the result of the conventional test showed a Cu recovery of 45% for a grade of 22% Cu, reaching a maximum selectivity of 25% with a recovery of less than 20%. The results of the dilution test indicated a recovery of 60% for the same grade of concentrate (22% Cu). Benefits were also observed in Mo recovery and in a decrease in the content of insolubles. Based on this, it was decided to move forward with pilot tests with Jameson technology.

6. Jameson Cell Pilot Evaluation

Figure 8 shows a photograph of the Jameson pilot cell used in the pilot tests.

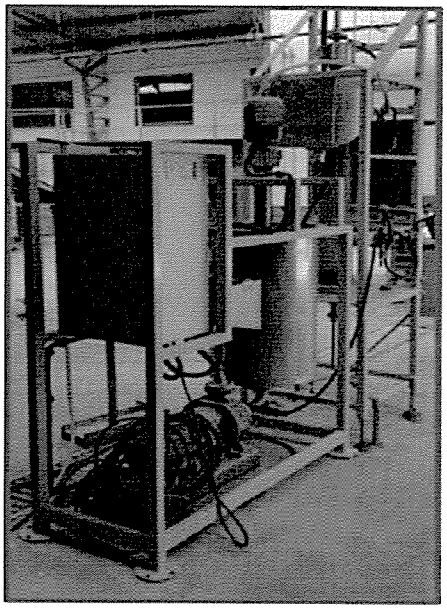

Figure 8: Jameson L150 Pilot Cell.

The pilot results in the Jameson cell, for the case of Cu, yielded concentrate grades of 27% Cu for recovery ranges between 40 and 70%. It should be noted that each point of the recovery vs grade curve corresponds to a design value for this type of technology. For design purposes, the selected grade recovery pair was 27% Cu/70% Rec Cu, as shown in Figure 9. It is important to note that this technology exceeds the potential grade of concentrate that could be obtained through the use of conventional technologies.

For this condition, the Mo result gave a concentrate grade of 0.99% Mo and a recovery of 80% Mo. For the INS, the final concentrate grade would be in the range of 4 to 5%. Au recovery is also favored as its grade increases from 3.2 g/t to 5 g/t.

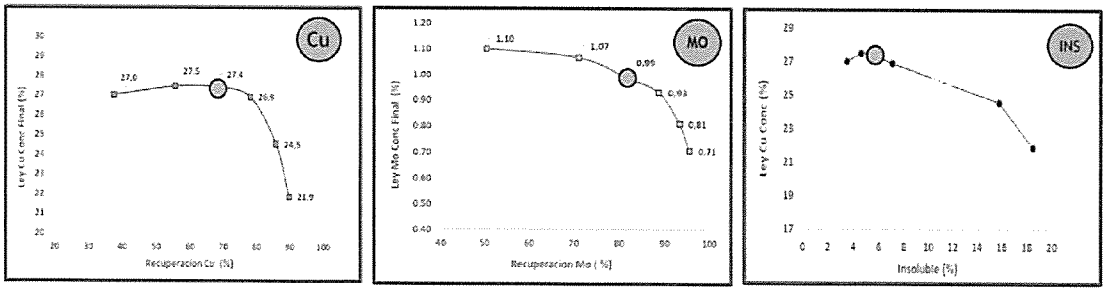

Figure 9: Pilot test results for Cu, Mo and Insolubles.

Based on the results obtained at the pilot level, flotation equipment is sized to obtain a 27%/70% for Grade/Recovery. The dimensioning carried out by Glencore Technology suggested that for this application, 2 cells model B5400/18 of 5.4 m in diameter and 18 downcomers. Figure 10 shows the design of the recommended cell for application in Minera Centinela.

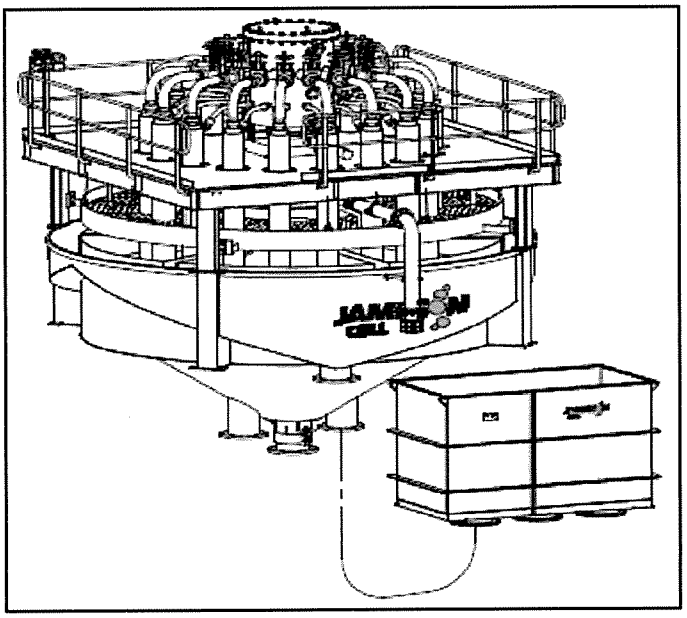

Figure 10: Jameson B5400/18 Minera Centinela cell design.

7. Flotation Fallback Project

With the flotation technology defined, in this case, pneumatic flotation through Jameson cells, an engineering study was developed, also considering the revision and improvement of the hydraulic capacity of the flotation circuit, so as not to generate restrictions in the mass transfer of intermediate concentrates from the different process stages.

The project has now completed the detailed engineering stage and is now in construction. It is expected that the installation of the new cleaner stage and start of commissioning will occur by the end of 2022.

The engineering design considers the development of facilities and infrastructure adapted to the particular conditions of the site, in order to safeguard the environment, the safety of people, equipment and the operation. The basic concepts of the project have also been configured based on the technical requirements imposed by the material to be processed, the process facilities and the optimization of capital and operating costs.

Figure 11 shows the flow diagram of the flotation circuit, including a second cleaning stage in Jameson cells.

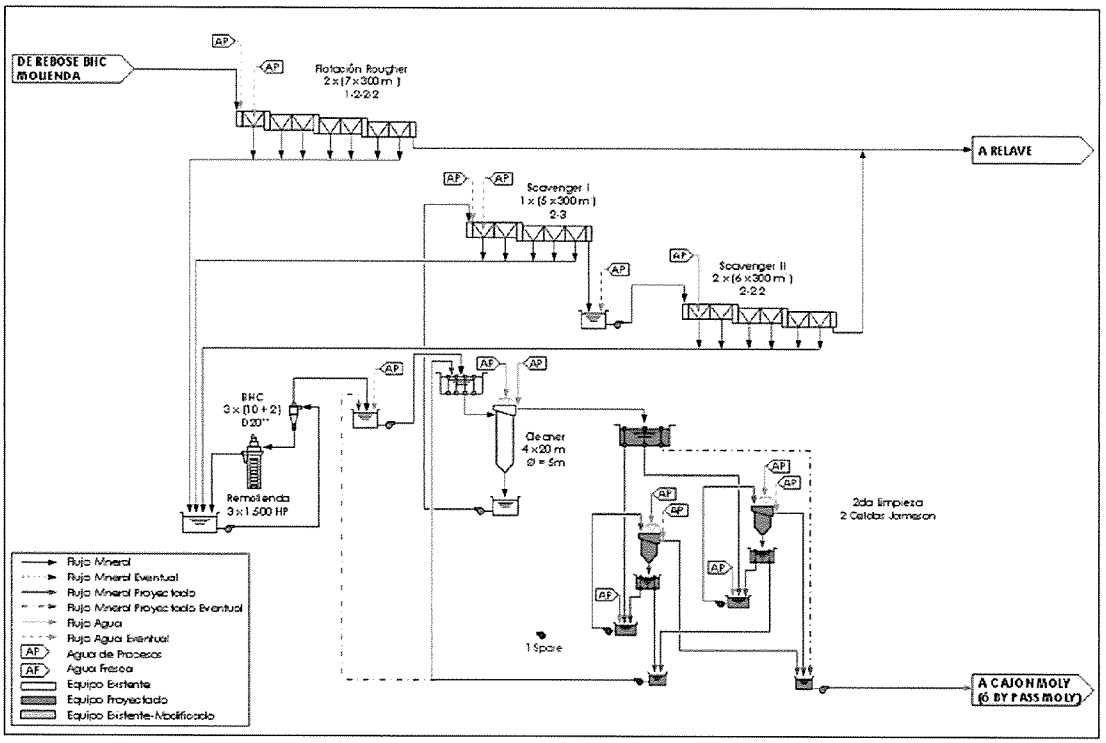

Figure 11: Projected Flow Diagram of Minera Centinela Collective Flotation Plant.

The projected second cleaning stage (Jameson cells) will be fed by column concentrate (current collective concentrate of the plant), which is expected to contain levels of 18 - 20% Cu and that can be enriched to values around 25 - 27%. The underflow from this stage will be returned to the column feed distributor box. Figure 12 shows the proposed location of the Jameson cells for this second cleaning stage within the collective flotation circuit.

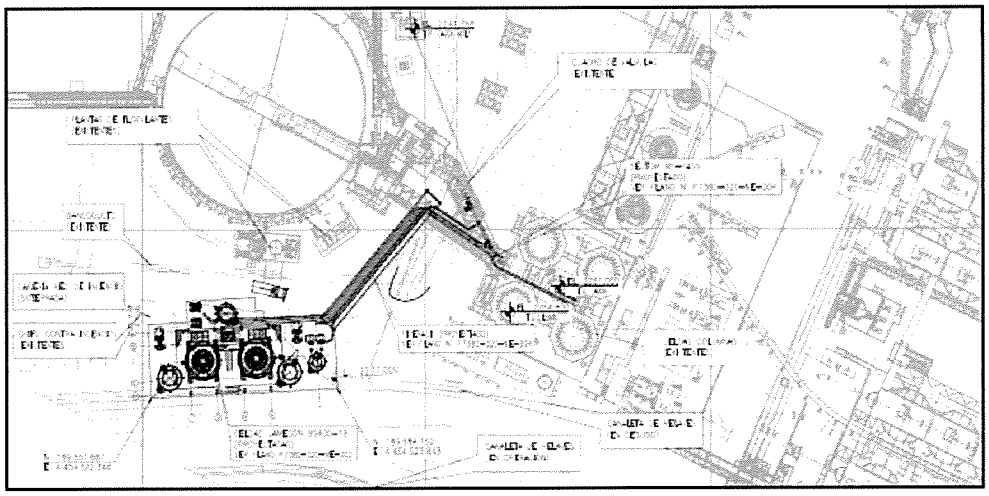

Figure 12: General Arrangement of Jameson Cells Collective Flotation

8. Final comments

Considering the difficulties of the ore that will be processed in the future and the existing challenges in the industry, Centinela carried out a series of specific studies focused on the use of an additional stage for the current cleaner circuit. Within these studies, in April 2021, an industrial test was carried out in the collective flotation stage with exclusive feed of the most complex minerals (low grade of copper and high level of pyrite). This test made it possible to identify improvement opportunities associated with recovery, by lifting the hydraulic restrictions of the flotation circuit and ratifying the potential that exists by adding a cleaning stage to improve the final concentrate grade.

Based on the final concentrates obtained in this industrial test, a series of tests with a pilot Jameson cell were commissioned to identify the maximum concentrate grade possible to achieve with this technology. Considering the promising results obtained, the design bases were generated for the future implementation of Jameson cells in the Centinela collective flotation circuit. This project is currently under construction and its commissioning is expected to occur by the end of 2022.

Finally, the expected benefits of the project are:

- Increase recovery of Cu in the collective stage due to alleviation of hydraulic restrictions.
- Increase collective concentrate grade from 1 to 2 w/w Cu and from 0.3 to 0.5 w/w Mo by incorporating Jameson Cells as a second cleaning stage.
- Stabilize and give greater continuity to the operation of the Mo plant due to an increase in grade in the Cu-Mo concentrate.