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Report on flotation pilot plant design and arrangement

D2.1

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ABBREVIATIONS AND ACRONYMS

EIP	European Innovation Partnership on Raw Materials

1. INTRODUCTION

INTMET is focused on a sustainable and efficient beneficiation of polymetallic, complex and low grade ores including tailings and wastes. The concept is to produce bulk concentrates or middling concentrates that will be efficiently treated through tailored leaching technology approach to produce added value refined metal (commodities) like Cu, Zn and other metals and critical materials (e.g. Au, Ag, In, Co). This novel hydrometallurgical process has the potential to treat existing complex or low grade concentrates from current operating mines, opening the way to a new and profitable mining business model. Effluents originated in the process will be reused and recycled, maximizing the recovering of dissolved metals. Besides, a very innovative hydroprocessing to valorize sulphur (producing fertilizers) and recover iron from pyrite secondary raw materials will be developed.

INTMET falls under the PolymetOre (EIP-RM Awarded Commitment) umbrella aiming to develop a sustainable and efficient solution to process polymetallic, complex and low grade ores to allow exploitation of resources that are unviable today by conventional routes due to their complexity or low grade. These valuable resources are abundant in some European mining regions in Spain, Portugal, Poland, Serbia, Sweden, Greece, etc. INTMET includes different innovative technologies to increase raw materials efficiency in EU mining business, allowing at the end unlocking a substantial volume of difficult ores that are currently unviable to treat through conventional ways.

An important part of the project is to develop the technological concept for bulk concentrate processing producing metals with high recovery at low cost and using an environmental friendly approach (Workpackage 2 of the INTMET Project). For that reason is necessary to define the proper route to produce above mentioned concentrate (nowadays only marketable sulphides concentrates are available in mineral processing industry: Cu concentrate, Zn concentrate & Pb concentrate). Tasks 2.1 & 2.2 of the project deal with improvement of technology for comminution and flotation to define the most suitable process to produce a bulk concentrate. And Task 2.3 consist on the work required to arrange a Flotation Pilot Plant that will produce the sample material for further testing in the different Workpackages of the project (WP3 atmospheric leaching- WP4 Pressure leaching – WP5 Bio-leaching).

The following text present the main results obtained during the works performed in Task 2.3 devoted to the design of the Flotation Pilot Plant.

2. FLOTATION OF SULPHIDE ORES

2.1 FLOTATION TECHNOLOGY

Froth flotation is a highly versatile method for physically separating particles based on differences in the ability of air bubbles to selectively adhere to specific mineral surfaces in a mineral/water slurry. The particles with attached air bubbles are then carried to the surface and removed, while the particles that remain completely wetted stay in the liquid phase. Froth flotation can be adapted to a broad range of mineral separations, as it is possible to use chemical treatments to selectively alter mineral surfaces so that they have the necessary properties for the separation.

FIGURE 1. FLOTATION LAB CELL

Flotation is currently in use for many diverse applications, with a few examples being: Separating sulfide minerals from silica gangue (and from other sulfide minerals); Separating potassium chloride (sylvite) from sodium chloride (halite); Separating coal from ash-forming minerals; Removing silicate minerals from iron ores; Separating phosphate minerals from silicates; And even non-mineral applications such as de-inking recycled newsprint. It is particularly useful for processing fine-grained ores that are not amenable to conventional gravity concentration.

The Flotation System Chemistry Components are mainly: Collectors, Frothers, Activators, Depressants and pH. Operation Components are Feed Rate, Mineralogy, Particle Size, Pulp Density and Temperature. Equipment Components are Cell Design, Agitation, Air, FlowCell, Bank Configuration, and Cell Bank Control.
The Industrial flotation system includes many interrelated components, and changes in one area will produce compensating effects in other areas.

FIGURE 2. INDUSTRIAL FLOTATION PLANT

2.2 FLOTATION REAGENTS

A number of organic and inorganic reagents are used in flotation processes to achieve the desired separation. These can be classified into collectors, frothers, extenders, activators, depressants, deactivators, flocculants and dispersants.

Collectors

The primary role of collectors is to adsorb selectively in order to impart hydrophobicity to particles of the mineral to be floated. Having this dual ability to adsorb and to impart hydrophobicity requires the collector molecule to contain two functional parts:

- A nonpolar group of sufficient hydrophobicity. For sulphides flotation the nonpolar group is usually a short-chained hydrocarbon (2-15 CH_2 or CH_3 groups).
- A polar or ionic group that will be electrostatically or chemically reactive toward species on the mineral surface. This polar part is usually anionic sulphate, sulfonate, phosphate, carboxylate, oxime or thiocarbonate, cationic amine or non-ionic oximes.

Following tables give examples of collectors used in froth flotation:

Amine	Formula
n-amyl amine	$C_5H_{11}NH_2$
n-dodecylamine	$C_{12}H_{25}NH_2$
Di-n-amylamine	$(C_5H_{11})_2NH$
Tri-n-amylamine	$(C_5H_{11})_3N$
Tetramethylammonium chloride	$[(CH_3)_4N]^+Cl^-$
Tallow amine acetate	RNH_3Ac (96% C_{18})

TABLE 1. CATIONIC COLLECTORS

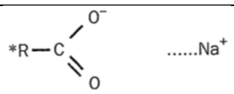
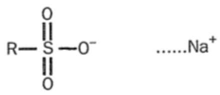
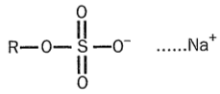
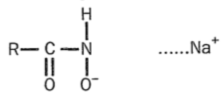
Collector	Structural Formula
Carboxylate	
Sulfonate	
Alkyl sulfate	
Hydroxamate	

TABLE 2. STRUCTURAL FORMULAS OF SODIUM SALTS OF ANIONIC COLLECTORS

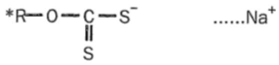
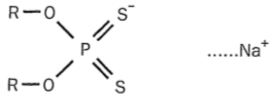
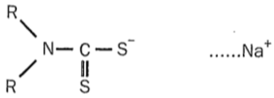
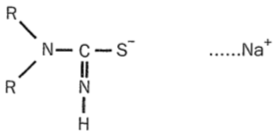
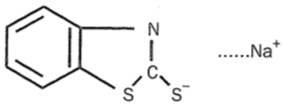
Collector	Structural Formula
Xanthate	
Thiophosphate	
Thiocarbamate	
Mercaptan	
Thiourea	
Mercaptobenzothiazole	

TABLE 4. ANIONIC SULFHYDRYL COLLECTORS

Collection by these reagents depends on properties as ionization, solubility, critical micelle concentration or emulsifying power:

- A highly soluble surfactant has a low tendency to depart from the solution and adsorb on interfaces.
- The tendency to form micelles also influences the utility of the collector for flotation. The surfactant forms micelles when its bulk concentration reaches the "critical micelle concentration" (CMC). Above the CMC, properties of the surfactant solutions change, as surface tension of water, which decreases up to the CMC and remains approximately constant above CMC, which indicates that the activity of the surface-active monomer species is constant above the CMC and the micelles themselves are not-surface active.

Additionally, the solubility of salts formed by surfactants with mineral dissolved species and other additives can have an important influence on the extent of flotation. Nevertheless, precipitation can also occur on the mineral surface and lead to good flotation.

<u>Frothers</u>

To achieve an adequate flotation, bubbles that rise to the top of the flotation cell must not break until they are skimmed off to collect the floated particles. This is the reason why non-ionic surfactants are usually added to produce the desired stability of the froth. This may happen that a collector can act as a frother, such is the case of long-chained collectors which will adsorb also at bubble surface in sufficient amounts to achieve an elastic surface and stable bubbles. On the other hand, short-chained chemicals used as collectors, additional reagents must be added for froth stability.

Common frothers are cresylic acid, MIBC polyglycols or pine oil, whose constituent are xylenol, methyl isobutyl carbinol, polypropylene and terpineol respectively.

Extenders

In addition to frothers and collectors, non-ionic and nonpolar surface-active agents are used in to enhance the hydrophobicity of the particles and the resultant flotation recovery. These reagents act by forming a multilayer coating on the already partly hydrophobic surfaces. They can also act like frothers by co-adsorbing with collectors.

Activators

Many minerals do not adsorb collectors, so the special reagents are necessary to activate their adsorption. So, an activator normally acts by adsorbing on the mineral, providing sites for adsorption of the collector species. As example, copper sulphate acts as an activator for the flotation of sphalerite using xanthate as a collector at relatively low concentration. Copper ion exchanges for zinc ion of the mineral surface, and the sphalerite particle then behaves in flotation like a copper sulphide particle.

Depressants

Depressants retard or inhibit flotation of a desired solid. The depressing agent is adsorpted on the particle surface, which pre-empts the collector from adsorbing and masks the adsorbed collector from the bulk solution and achieves the particle does not exhibit a hydrophobic exterior. Chemicals used as depressants include multivalent ions as phosphate, silicates, chromates, aluminium salts or organics. Common examples include starch, tannin, quebracho and dextrin.

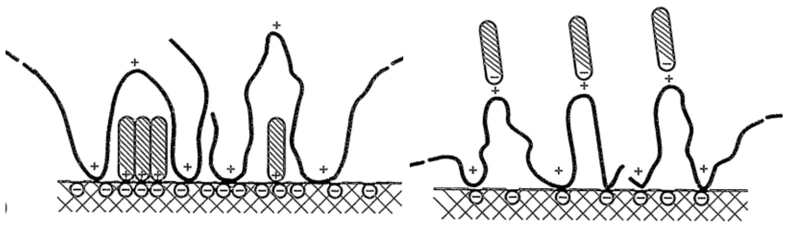


FIGURE 3. CO-ADSORPTION ON MINERAL PARTICLES RESULTING IN THEIR FLOTATION DEPRESSION AND RESULTING IN THEIR FLOTATION ACTIVATION

Figure above illustrates depression of flotation through action of a cationic polymer; the same polymer can activate flotation using an anionic collector.

Deactivators

Deactivators react with activators to form inert species and prevent flotation.

Dispersants and flocculants

Flotation is often hampered by the presence of fine particles or slimes, which can coat the coarser mineral particles and consume excessive amounts of reagent because of their large specific surface areas. To solve this problem dispersants are used in order to disperse these slimes.

Flocculants are used to deal with fines. Polymers are used to flocculate particles into larger aggregates or flocs by forming bridges between them. On mineral particles, adsorption of polymers is attributed to hydrogen bonding between functional groups, or chemical or electrostatic bonding between polymer functional groups and surface sites. Then, it is followed by separation of the flocs.

pH as Modifier

The pH in the pulp is a key variable to maximize recovery and selectivity, so it must be carefully controlled. Lime, sodium hydroxide, sodium carbonate, ammonia, hydrochloric acid or sulphuric acid are used to control pH.

2.3 INDUSTRIAL FLOTATION EQUIPMENT

The purpose of flotation machines is to ensure the flow of the pulp into good, active contact of particles with bubbles and the levitation of mineral-laden air bubbles to the top of the cell, allowing the removal of entrapped particles.

A mechanical flotation cell consists of a vessel or a tank fitted with an impeller or rotor. The impeller agitates the slurry to keep particles in suspension, disperses air into fine bubbles and provides an environment in the cell tank for interaction of bubbles and hydrophobic particles and separation of valuable mineral particles from the undesired gangue mineral particles.

The major manufacturers and different design features of flotation cells to be highlighted at present are the following described below.

Bateman Cell

Bateman flotation cells (BQR serie) have a round tank design (cell sizes vary from 5 m^3 to 100 m^3). The mechanism of these cells consists of a hemispherical-shaped impeller connected to a solid drive shaft. The impeller has no disc on the top, so the blades are opened top and bottom opened. The drive shaft is shrouded with a stand pipe. Through the gap between the standpipe and the shaft air is supplied into the mechanism by a forced entry mode. It also has an overhung-type stator which is connected to the bottom of the standpipe and composed of a horizontal hood with baffle plates projecting downwards.

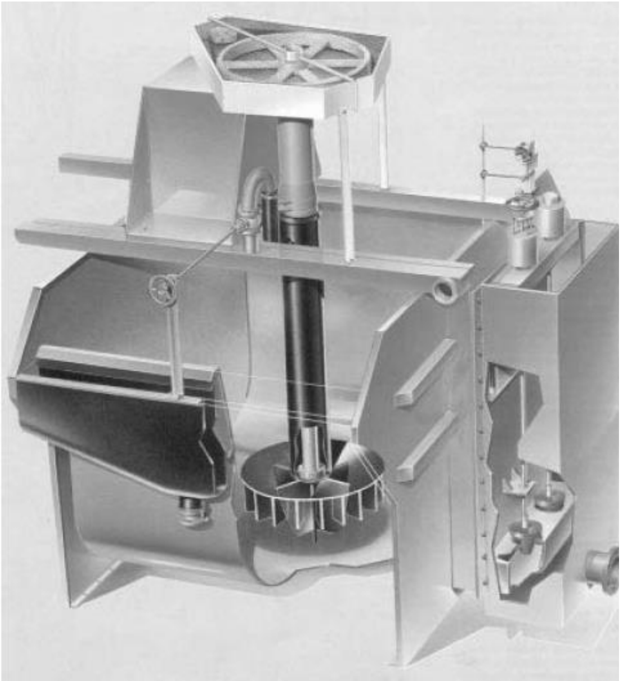


FIGURE 4. BATEMAN FLOTATION CELL DIAGRAM

Dorr-Oliver Cells

The Dorr-Oliver cell is marketed by FLSmidth Dorr-Oliver Eimco in a wide range of sizes, form 0.03 m^3 to 200 m^3. Cell tanks on all large Dorr-Oliver flotation cells are truncated, conical bottom, round tanks or U-shaped in cross-section. Corners are eliminated, and the conical bottom or U-shape helps to feed slurry into the pump action of the rotor and prevent shortcircuiting.

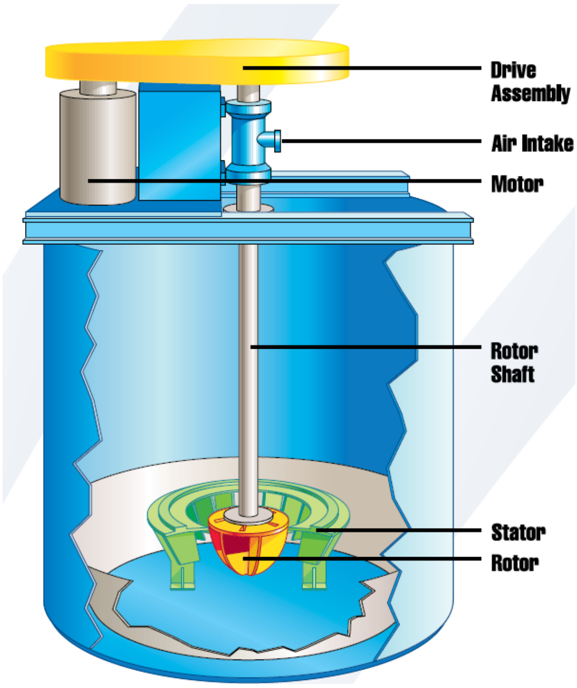


FIGURE 5. DORR-OLIVER FLOTATION CELL DIAGRAM

This mechanism consists of a hemispherical-shaped impeller fitted to a hollow shaft. Air is introduced to the impeller through the hollow shaft, being a forced air entry mode. Stators are generally mounted on the bottom but in the large cells mechanisms these are overhung.

<u>Wemco Cells</u>

Wemco has long been a trusted and proven leader in flotation technology under the FLSmidth Dorr-Oliver Eimco brand.

There are two major Wemco designs, the Wemco 1+1 and new SmartCell:

- The SmartCell Flotation series combines the proven Wemco mechanism with cylindrical cells to optimize energy input, aeration and mixing. This configuration reduces pulp turbulence and improves froth stability. Sizes range goes from 0.05 m^3 to 300 m^3.

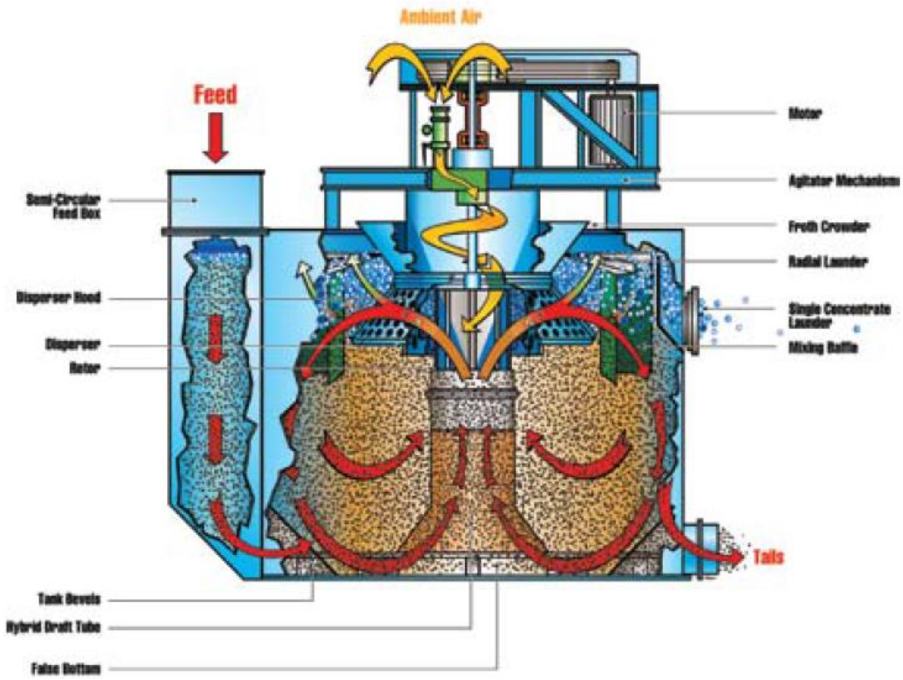


FIGURE 6. WEMCO SMARTCELL DIAGRAM

- The Wemco 1+1 design comes in cells from 0.03 m^3 to 85 m^3. Airflow into the pulp is self-induced by the turning rotor and no forced air supply is required. This design consists of a rotor, disperser, standpipe and a hood. Lager cells are designed with a false bottom and draught tube.

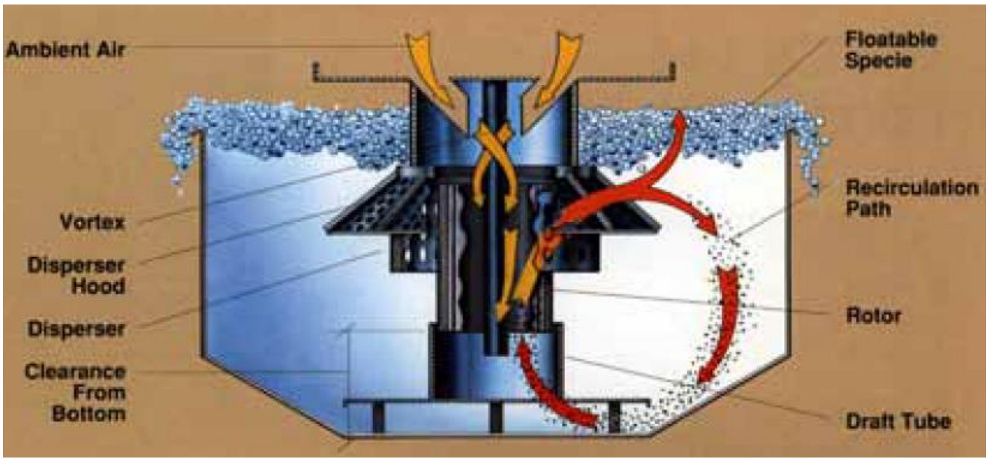


FIGURE 7. WEMCO 1+1 DIAGRAM

In both Wemco cells, rotor size, speed and submergence in the pulp determine the air and pulp circulation into the cell. Therefore, liquid circulation and air transfer are function of rotor speed, size and submergence.

Outokumpu Cells

Outokumpu produces different flotation machines which can be categorized as:

1. OK conventional flotation machines: for rougher, scavenger and cleaner flotation.
2. TankCell flotation machines: for rougher and scavenger flotation.
3. SkimAir flotation units: for flash flotation.
4. High-Grade flotation machines: for cleaner flotation.

OK conventional flotation cells are available in volumes up to 38 m^3. Conventional cells have a rectangular tank design for cells up to 3 m^3 and U-shaped tank above 3 m^3 and up to 38 m^3.

TankCell designs are available from volumes of 5 m^3 to 500 m^3. These cells are cylindrical with flat bottom.

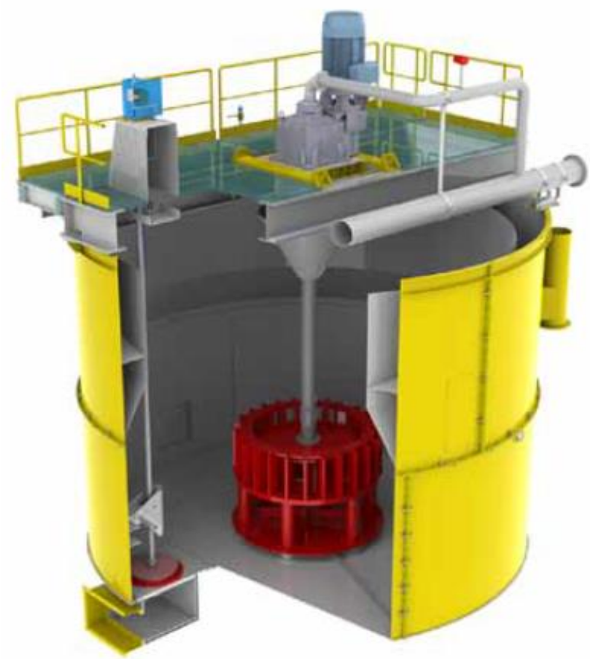


FIGURE 8. OUTOKUMPU TANKCELL DIAGRAM

SkimAir flotation units are used as a standalone cell in a one-stage process for producing high grade concentrates. These cells are cylindrical with conical bottom.

The impeller mechanism is designed with a hemispherical-shaped impeller with a disc on the top attached to a number of narrow vertical slots tapered downwards. It has separate slots for air and slurry movement.

These machines have a forced air entry mode in which air is brought into the impeller through a hollow shaft.

The stator is mounted on the bottom of the tank. There are two different designs: MultiMix and FreeFlow. First is typically used for fine particle flotation, whereas the second one is typically used for coarse particles flotation.

FloatForce mechanism is a new mechanism which maximizes bubble and particle contact in the shear zone between the rotor and stator. The strong shear forces produce sufficient energy for fines to break through the water film energy barrier on the air bubbles. This mechanism is available for OK, SkimAir and TankCell equipment and replace MultiMix and FreeFlow mechanisms.

<u>Metso Cells</u>

The DR range include cells in sizes from 0.09 m^3 to 36 m^3. These machines are open type and incorporate a vertical circulation of pulp combining a “recirculation well” with the distinctive top feed impeller. This arrangement provides positive vertical circulation of pulp similar to the action in a propeller agitator.

The RCS flotation machine comes in sizes from 0.8 m^3 to 200 m^3 and utilizes a new DV (deep vane mechanism). This mechanism consists of vertical rectangular blades or vanes tapered at the bottom. The blades are connected to a circular horizontal disc located above the centre of the blades. The mechanism is designed with an overhung stator with vertical vanes projecting downwards connected to the mechanism standpipe.

FIGURE 9. RCS FLOTATION MACHINE

2.4 INDUSTRIAL FLOTATION PROCESSES

Current industrial flotation processing for Metals recovery are focused on separate commercial concentrates to be used on Copper, Zinc and Lead refineries. Depending on the feed ore different reagent combination and flotation stages (including grinding and regrinding) are used. In the case of sulphides one of the major issues is the pyrite content in the ore that must be depressed in the flotation process for purification purpose. In the case of zinc the necessity of an activator as copper sulphate is the base for an effective metal recovery. Different reagents combinations are used (collectors, modifiers, etc) with the aim of producing the final concentrates.

In the next figures the diagrams showing concentrates production from different raw materials are presented.

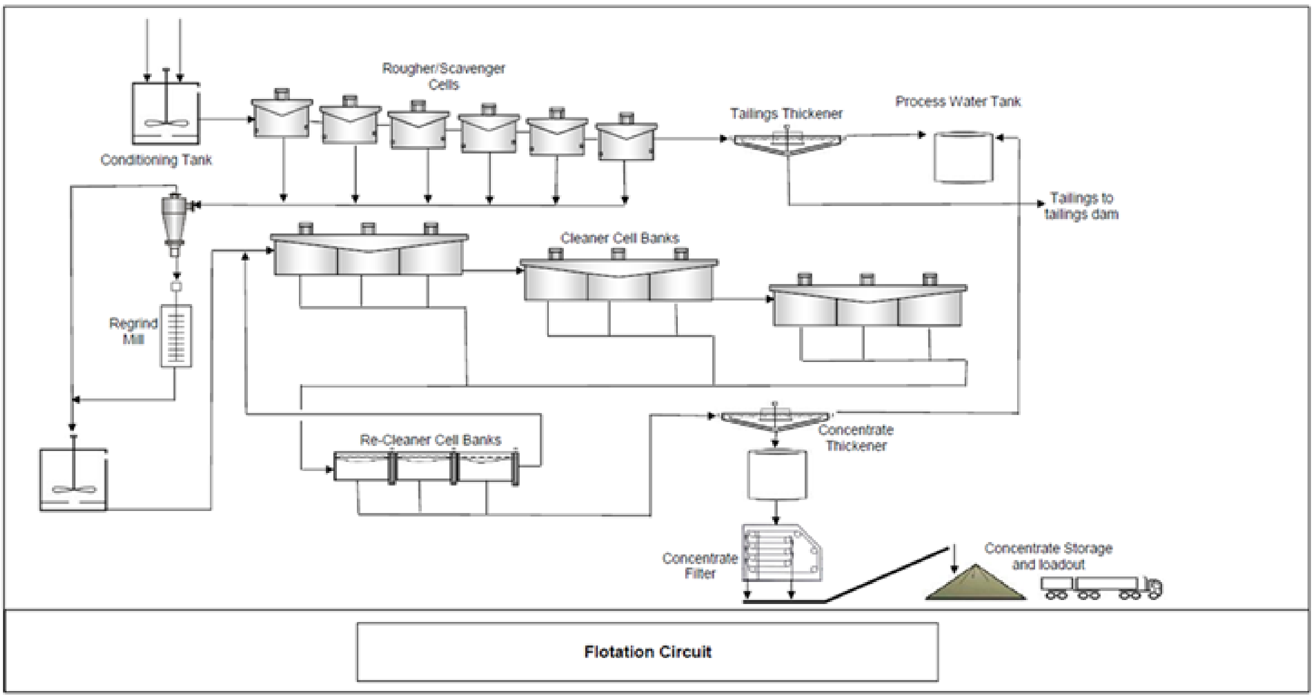


FIGURE 10. COPPER CONCENTRATE FLOTATION FLOWSHEET

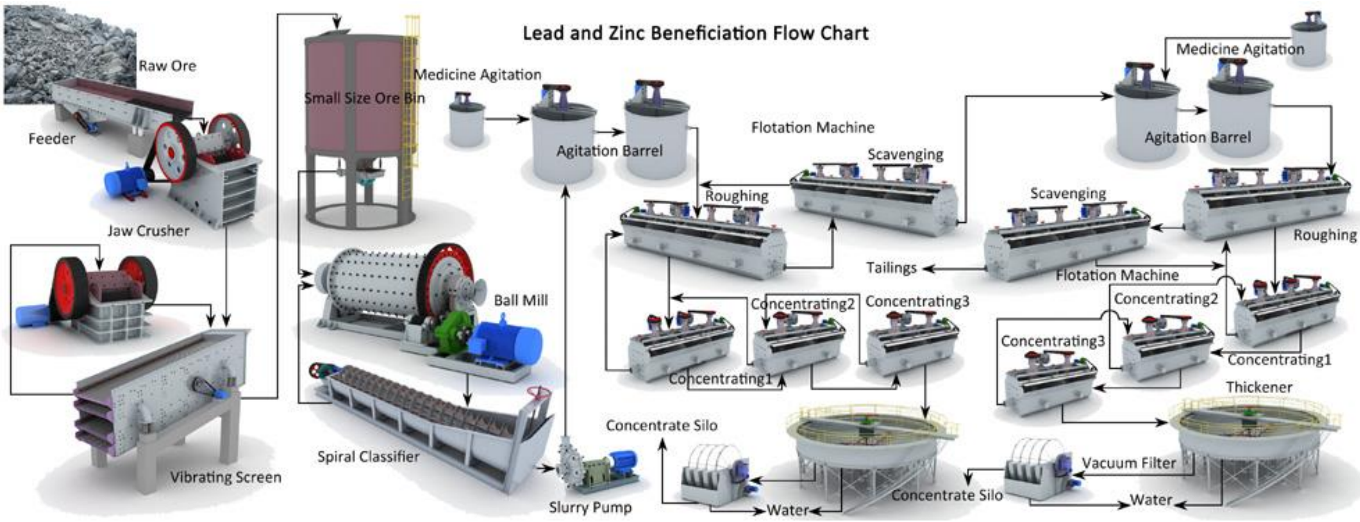


FIGURE 11. LEAD & ZINC CONCENTRATES FLOWSHEETS

Main stages included in all the processing routes are: Conditioning, Rougher, Scavenger, Cleaning, thickening and Filtration. Grinding and Regrinding (including the necessary classification operation unit) stages are needed to ensure mineral liberation from gangue.

3. BULK FLOTATION PILOT PLANT DESIGN

In accordance with the objectives of the INTMET project the high recovery of metals from polymetallic and complex ores are needed. Producing separate commercial concentrates, as current technology does, metals recovery are low and, at the same time, processing cost are high. For that reason bulk concentrate production is the best option and the flotation pilot plant must be designed with this final aim.

3.1 DESIGN BASIS

Main design basis for pilot plant design are as follows:

- Feed capacity: 1000 kg/h of crushed ore
- Feed ore properties:

Description	ORE-FEED
KG/HR SOLIDS	1000.0
KG/HR AQUEOUS	40.0
KG/HR TOTAL	1040.0
Sp.Gr.SOLIDS	4.7
Sp.Gr.AQUEOUS	1.0
Sp.Gr.TOTAL	4.1
Sol/Liq lph	251
P80-mm	10
Temperature	25.0
%Cu Solid	1.5
%Zn Solid	3.0
%Pb Solid	1.6
ppm Ag Solid	34.8

- Grinding Size Production: 100-35 microns (adjustable)
- Regrinding Size: Up to 10 microns (adjustable)

3.2 PROCESS BLOCK DIAGRAM

The conceptual flow diagram for the bulk concentrate production is presented in the following figure.

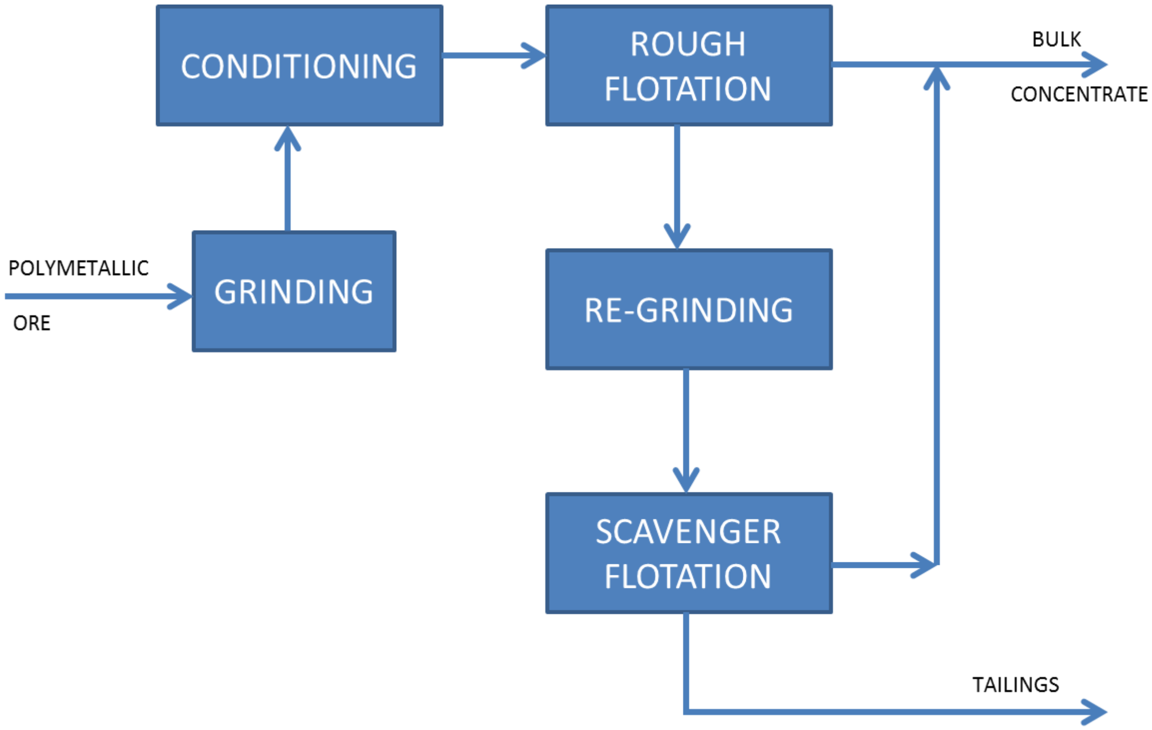


FIGURE 12. BULK FLOTATION BLOCK DIAGRAM

The crushed ore is send to a grinding stage in order to produce the first liberation of the mineral for rough flotation, as described before the particle size could be adjusted to fine tune the flotation process. After grinding, a conditioning stage is used, where flotation additives and air are used to promote an effective flotation of desirable metals. In the rough flotation stage major part of metals are recovered in the froth and the tailings are re-grinded in order to produce the proper size for further recovery of the metals. Finally the froth stream from scavenger flotation is send with the previous froth stream producing the bulk concetrate

3.3 PILOT PLANT LAYOUT

The Flotation Pilot Plant will be arranged in two main levels, ground level will contain mainly Bins, Tanks, Mills and Pumps. In the second level flotation machines and reagents will be installed. In the following figures the arrangement of the main equipment are showed.

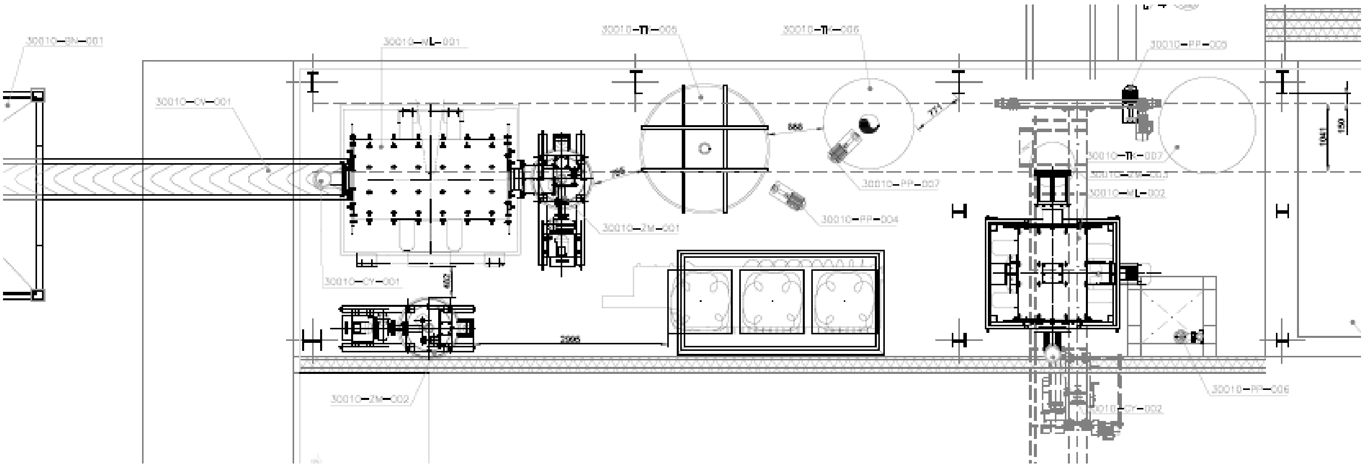


FIGURE 13. PILOT PLANT FLOOR LEVEL

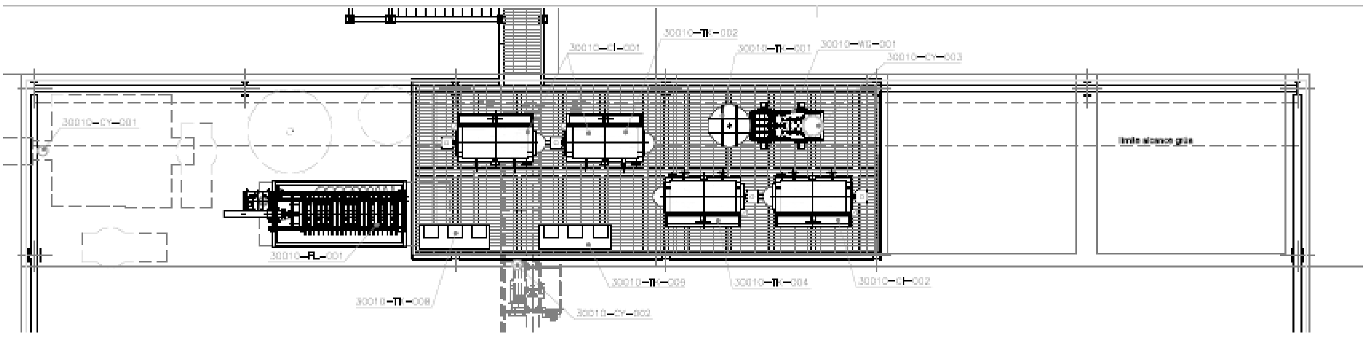


FIGURE 14. PILOT PLANT SECOND LEVEL

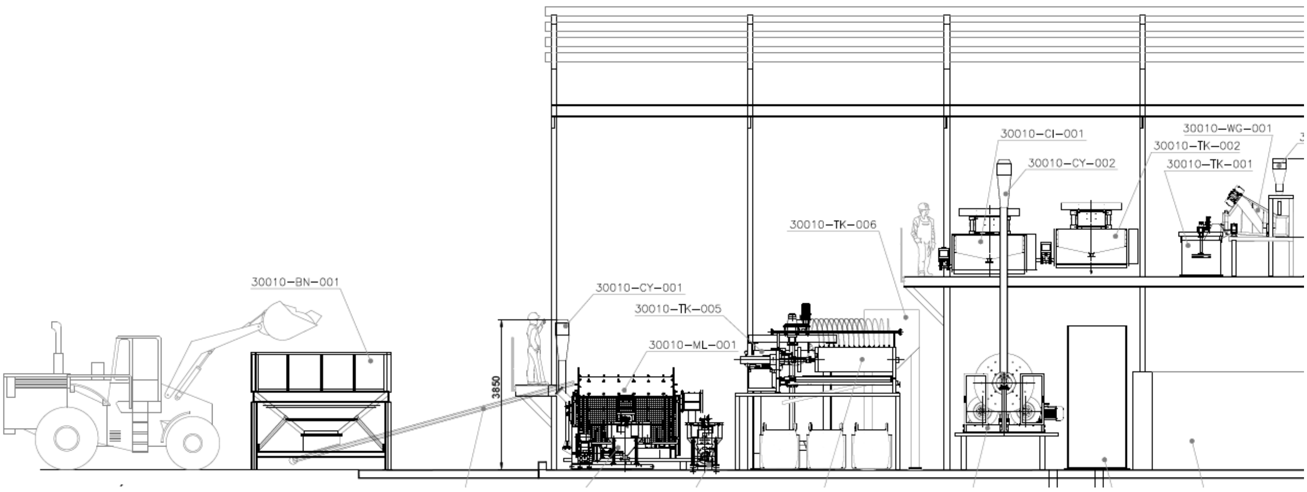


FIGURE 15. PILOT PLANT SIDE VIEW

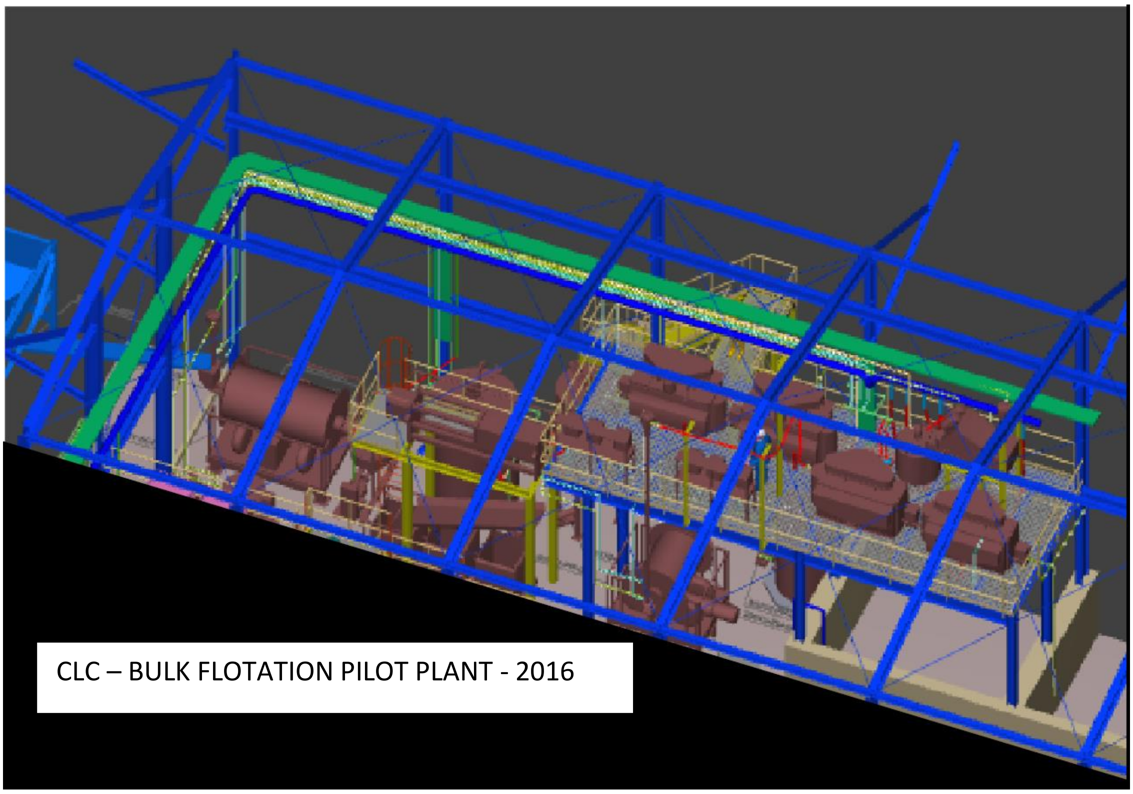


FIGURE 16. PILOT PLANT 3D VIEW

3.4 INSTALLATION

During the beginning of 2016 the engineering of the building and its construction was performed by CLC. The building was designed to install the Flotation Pilot Plant and the Atmospheric Leaching Pilot Plant. The following figure show the building under construction.

CLC Pilot Plant Under Construction April 2017

FIGURE 17. BUILDING UNDER CONSTRUCTION

Currently the majority of the equipment is installed and it is expected to be ready for start-up at early July. In the following pictures some equipment installed in the building are showed.

In Figure 17, a main view of the building during equipment erection and installation is showed. Right top the re-grinding mill is on installation process.

Next figures (18 & 19) shows the Flotation Pilot Plant with all the main equipment installed: Feed Bin and Belt Feeder, Ball grinding Mill, Flotation Cells, Re-Grinding Mill, Concentrate Thickener and Concentrate Filter as the final equipment of the process.

FIGURE 18. EQUIPMENT INSTALLATION JUNE 2016

FIGURE 19. PILOT EQUIPMENT DETAILS

4. CONCLUSIONS

Main result of deliverable 2.1 is that a flotation pilot plant with a maximum capacity of 1000 kg/h ore feed will be available for fresh concentrate production at early July in Cobre Las Cruces Mining.

The Bulk Concentration Pilot Plant Facility will consist mainly in a Rough Flotation after the first Grinding Stage. In a second phase tailings from previous flotation stage is sent to a re-grinding stage to produce an effective mineral liberation for metals recovery. Finally the second flotation stage produces a scavenger concentrate to be mixed with the rougher to produce the bulk concentrate. Tailings containing high level of pyrite will be also one stream of the plant and consequently will produce a sample for further testing in Iron/Sulphur recovery studies.

The pilot plant versatility, in terms of reagents dose and types, stream flows disposition and particle size ranges will ensure the production of most promising concentrates, for further leaching tests in WP3, WP4 & WP5 and at the same time producing tailings for WP6 testing.

Finally it must to be highlighted that due to the previous mentioned work in Deliverable 2.1 the Milestone MS3 " Flotation Plant Arrangement" is in the best way to be accomplished in M6 as originally scheduled by producing the proper adjustments in the installed Pilot Plant.