Challenges of Processing Sulphide Copper Ore Tailings Aiming at Minimizing the Occurrence of Acid Mine Drainage and Metal Leaching

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AGENDA

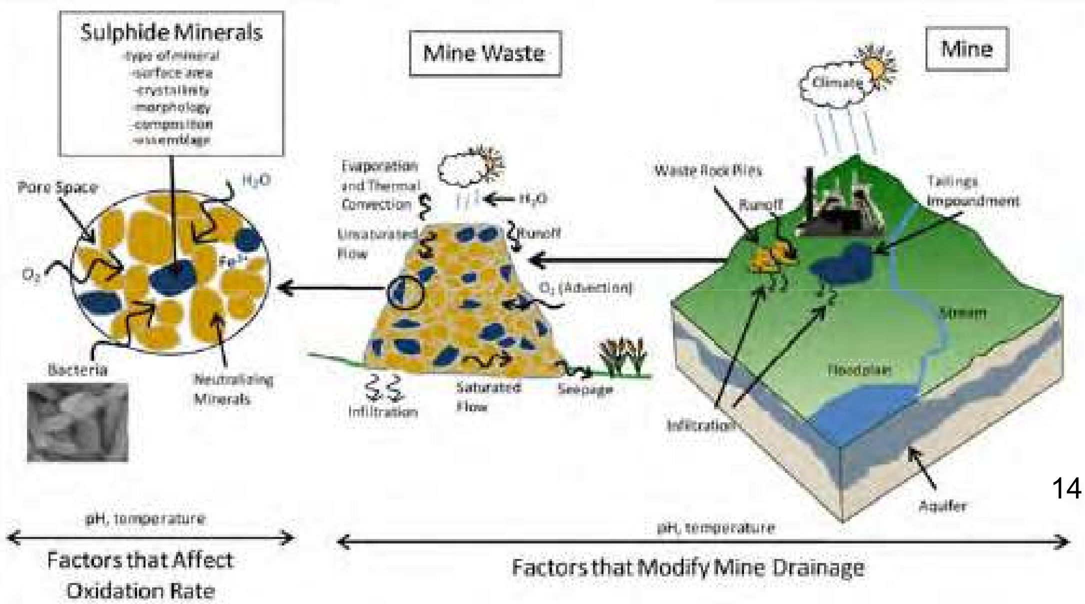
- INTRODUCTION.
- COPPER TAILING GENERATION.
- VALE´S MINERAL DEVELOPMENT CENTRE INFRASTRUTURE.
- CASE STUDY RESULTS.

INTRODUCTION

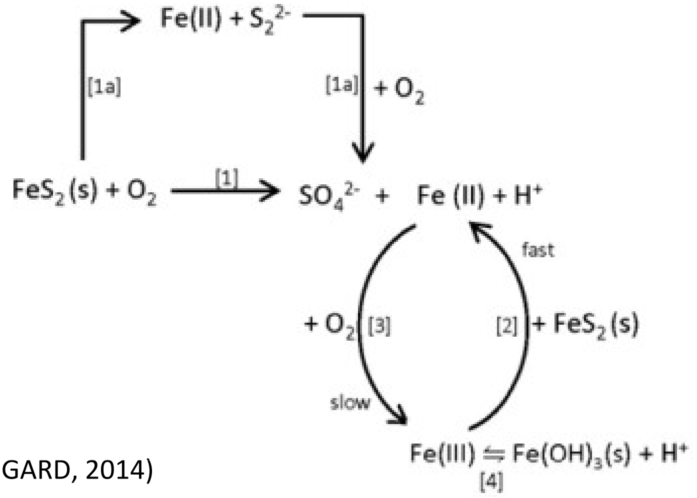
- Copper is an important metal in the construction, appliance, and energy industries.
- Main Cu-bearing minerals aiming the production of copper metal are chalcopyrite (**$CuFeS_2$**), bornite (**Cu_5FeS_4**), chalcocite (**Cu_2S**), enargite (**Cu_3AsS_4**), and covellite (**CuS**).
- Most copper sulphides mines generate a large amount of tailing after its concentration (flotation).
- The copper tailings have been either piled up or stored in dams, which requires complex structures and huge investment, as well as cost-effective maintenance and environmental fees.
- It is worthwhile to mention that the storage of copper tailings in dams also represents a threat to the surrounding environment.
- Copper flotation tailings contain a significant amount of non-copper sulphides minerals and a low amount of copper sulphides minerals that can generate effluent resulting from the oxidation of sulfides when they are exposed to oxygen and water.
- Low mine water pH will occur if the rate of acid generation due to sulfide oxidation is more than acid consumption by neutralizing minerals.

(GARD, 2014)

INTRODUCTION



(GARD, 2014)



(GARD, 2014)

$$\mathbf{FeS_{2(s)}} + 3.5O_{2(g)} + H_2O_{(l)} \rightarrow \mathbf{Fe^{2+}_{(aq)}} + 2SO_4{}^{2-}{}_{(aq)} + 2H^+_{(aq)}$$

$$\mathbf{Fe^{2+}_{(aq)}} + 0.25O_{2(g)} + H^+_{(aq)} \rightarrow 0.5H_2O_{(l)} + Fe^{3+}_{(aq)}$$

$$14Fe^{3+}_{(aq)} + FeS_{2(s)} + 8H_2O_{(l)} \rightarrow \mathbf{14Fe^{2+}_{(aq)}} + 2SO_4{}^{2-}{}_{(aq)} + 16H^+_{(aq)}$$

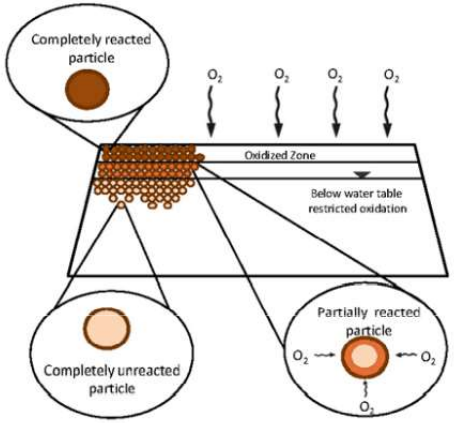
$$\mathbf{CuFeS_{2(s)}} + 4O_{2(g)} + 3H_2O_{(l)} \rightarrow Cu^{2+}_{(aq)} + Fe(OH)_{3(s)} + 2SO_4{}^{2-}{}_{(aq)} + \mathbf{3H^+_{(aq)}}$$

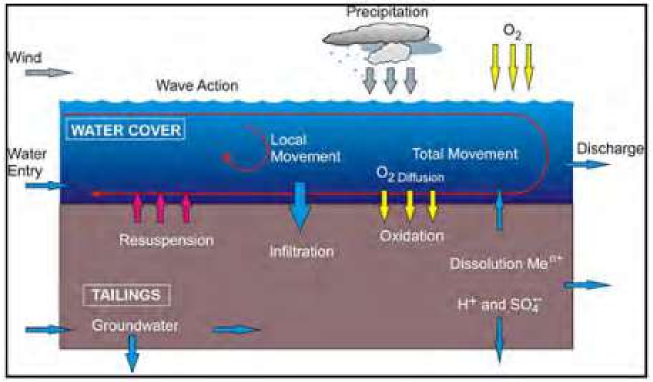
$$\mathbf{4Cu_5FeS_{4(s)}} + 4H_2O_{(l)} + 2O_{2(g)} \rightarrow 4Cu_5S_{4(s)} + 4Fe^{2+}_{(aq)} + 8OH^-_{(aq)}$$

$$Cu_5S_{4(s)} + 10H^+_{(aq)} + 5/2O_{2(g)} \rightarrow 5Cu^{2+}_{(aq)} + 4S_{(s)} + 5H_2O_{(l)}$$

Other sulphides minerals: Pyrrhotite ($Fe_{1-x}S$), Enargite (Cu_3AsS_4).

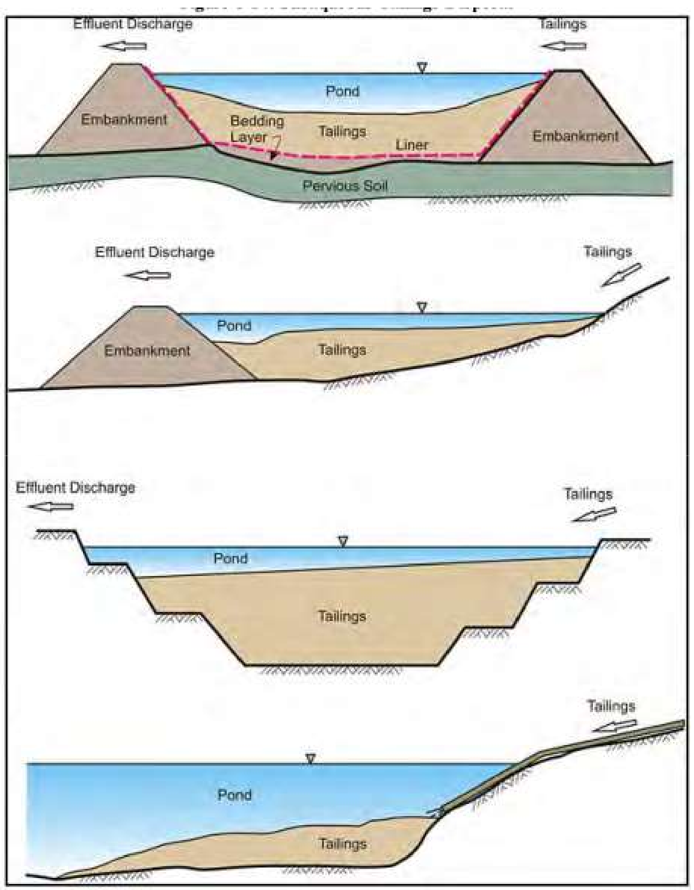
INTRODUCTION



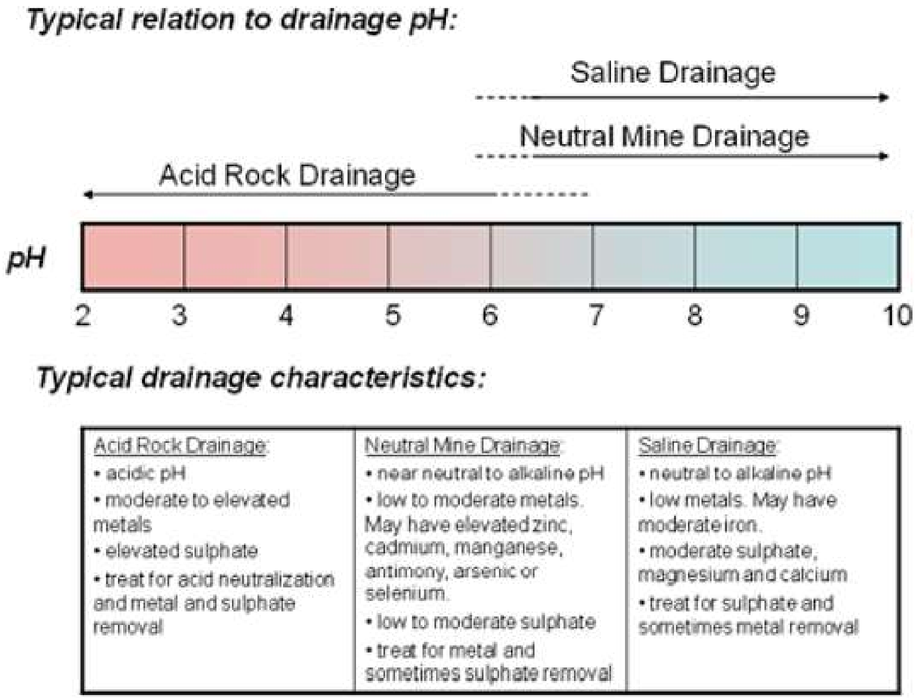


- ❖ Water covers limit the exposure of PAF (**Potential Acid Forming)** material to oxygen.
- ❖ Sufficient depth of water over PAF material must be provided to account for mixing of the water column and to prevent resuspension of wastes by wind or wave action.

(GARD, 2014)



INTRODUCTION



Acid Rock Drainage:	Neutral Mine Drainage:	Saline Drainage:
• acidic pH • moderate to elevated metals • elevated sulphate • treat for acid neutralization and metal and sulphate removal	• near neutral to alkaline pH • low to moderate metals. May have elevated zinc, cadmium, manganese, antimony, arsenic or selenium. • low to moderate sulphate • treat for metal and sometimes sulphate removal	• neutral to alkaline pH • low metals. May have moderate iron. • moderate sulphate, magnesium and calcium • treat for sulphate and sometimes metal removal

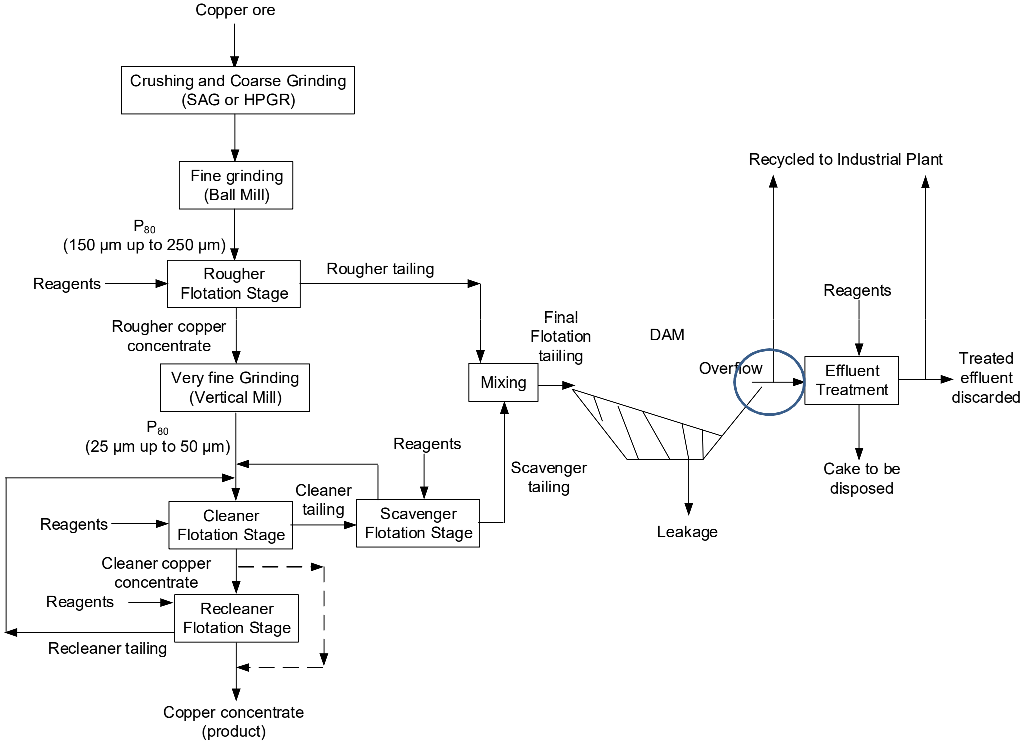
(GARD, 2014)

- ❖ The **drainage produced** from the oxidation process may be **neutral to acidic**, with or without dissolved metals, but always contains sulfate.

- ❖ When sufficient base minerals are present to neutralize the acid rock drainage, **neutral mine or saline drainages** may result form oxidation process.

- ❖ **Neutral mine drainage** is characterized by **elevated metals in solutions at circumneutral pH**, **while saline drainage** contains **high levels of sulfate at neutral pH without significant dissolved metals** concentrations.

COPPER TAILING GENERATION



Typical block diagram of copper flotation process route

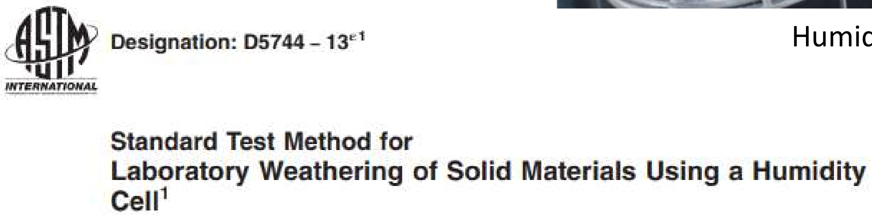
- ❖ Copper ore is crushed and ground to P_{80} between 150 and 250 µm to achieve the required liberation for the rougher flotation stage. In this step, it is expected to achieve the highest copper recovery.
- ❖ The rougher concentrate is submitted to regrind (P_{80} between 25 and 50 µm), followed by cleaner/recleaner flotation stage aiming to achieve the Cu grade desired.
- ❖ The cleaner tailing feeds the scavenger flotation stage. The rougher and scavenger tailings will form the final tailing that will be sent to the DAM.
- ❖ The DAM overflow effluent could be recycled to industrial plant or treated to generate the treated effluent that could be disposed or also recycled to the industrial plant.

VALE´S MINERAL DEVELOPMENT CENTRE INFRASTRUTURE

50 Humidity Cells Test (HCT), being 25 with height 20 cm and diameter 10 cm (Coarser samples) and 25 hct: Height 10 cm and Diameter 20 cm (Fines samples); 2 Air Dryer; 2 manifold with the capacity to run 38 humidity cells.

- To determine long-term weathering rates under oxygenated conditions.
- To evaluate lag time to acid generation.
- To provide reaction rates for geochemical modeling.
- Provides kinetic and steady-state leaching information and is recommended tests for determination of weathering rates of primary minerals.
- Not suitable to evaluate of saturated materials.
- Grain size reduction may increase reactivity.

Humidity Cells in operation in CDM

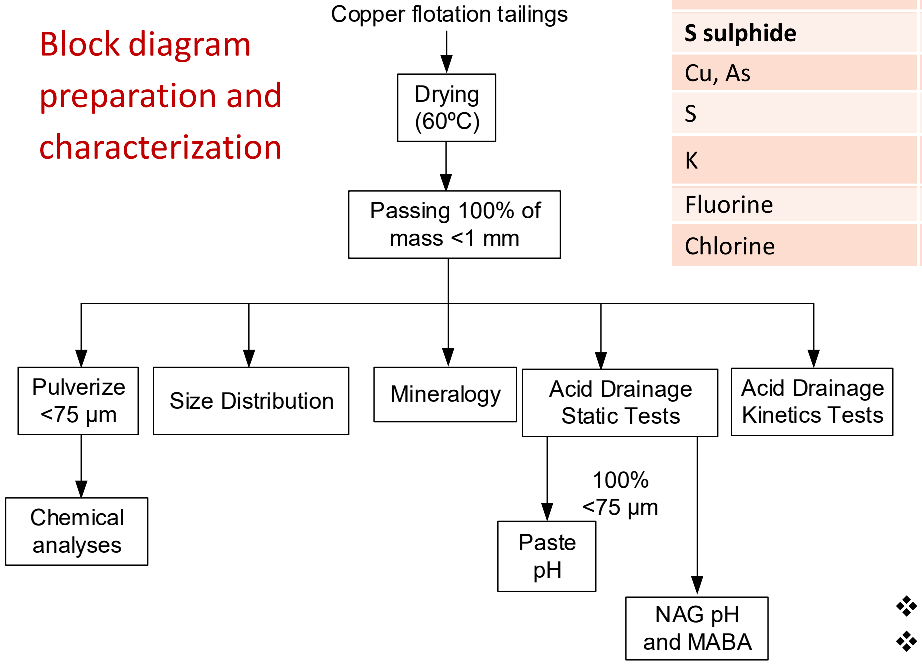

Designation: D5744 – 13$^{\varepsilon 1}$

Standard Test Method for
Laboratory Weathering of Solid Materials Using a Humidity Cell[1]

CASE STUDY RESULTS

Static Tests

Block diagram preparation and characterization


Copper flotation tailings
Drying (60ºC)
Passing 100% of mass <1 mm
Pulverize <75 µm
Size Distribution
Mineralogy
Acid Drainage Static Tests
Acid Drainage Kinetics Tests
Chemical analyses
100% <75 µm
Paste pH
NAG pH and MABA

Analytical procedures for assays for solids samples

Element	Analytical methodology
Ca, Mg, Al, Fe, Mn, P and Si	Calcination 600°C, fusion $Na_2CO_3/Na_2B_4O_7$, reading ICP-OES
S sulphide	**Leaching calcium carbonate, direct combustion, reading infra-red**
Cu, As	Total solubilization with aqua regia and reading ICP-OES.
S	Direct combustion and reading Infra-red from LECO.
K	Total solubilization in HCl + HF and reading ICP-OES.
Fluorine	Fusion KNO_3/KOH, dissolution water and reading selective ion electrode.
Chlorine	Fusion KNO_3/KOH, dissolution in water and titration with $AgNO_3$ solution.

Analytical procedures for assays for liquors

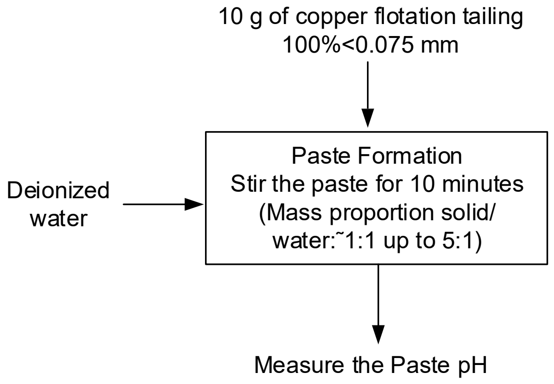
Element	Analytical methodology
Metals	USEPA Method 3005A (1992).
Anions	USEPA Method 300.0 (1993) and USEPA Method 300.1 (1997).
Alkalinity	SMWW, 23rd Edition - Method 2320 (2020).
Acidity	SMWW, 23rd Edition - Method 2310 (2018).

- Mineralogical: QEMSCAN. Mineral data were correlated with chemical assays.
- Size distribution followed conventional sieving for particles bigger than 45 µm and hydrocyclone loop for particles smaller than 45 µm.

CASE STUDY RESULTS

Static Tests

Paste pH



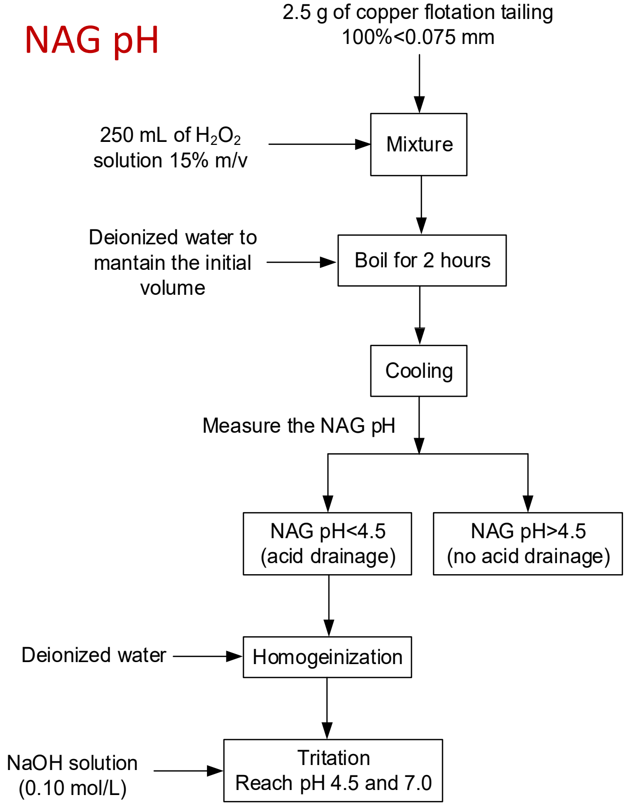
10 g of copper flotation tailing
100%<0.075 mm

Deionized water

Paste Formation
Stir the paste for 10 minutes
(Mass proportion solid/ water:˜1:1 up to 5:1)

Measure the Paste pH

NAG pH



2.5 g of copper flotation tailing
100%<0.075 mm

250 mL of H_2O_2 solution 15% m/v

Mixture

Deionized water to mantain the initial volume

Boil for 2 hours

Cooling

Measure the NAG pH

NAG pH<4.5
(acid drainage)

NAG pH>4.5
(no acid drainage)

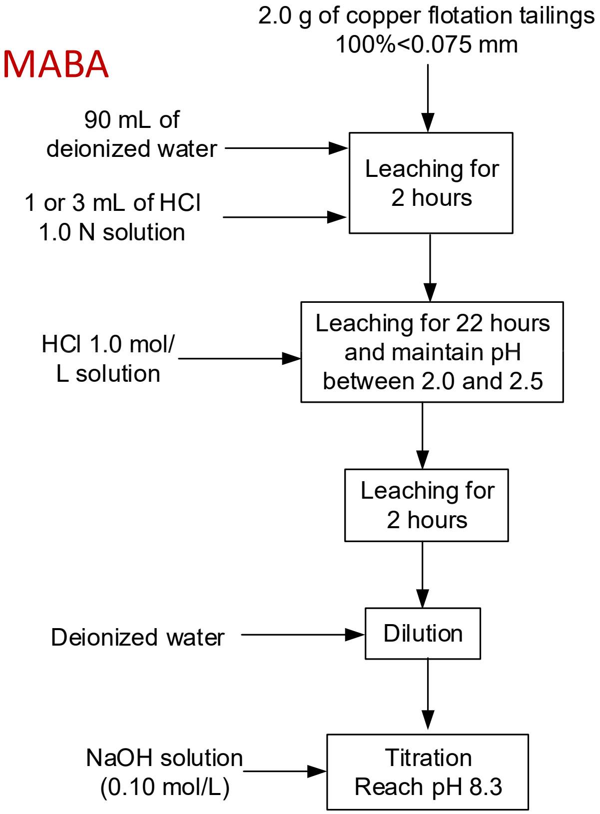
Deionized water

Homogeinization

NaOH solution
(0.10 mol/L)

Tritation
Reach pH 4.5 and 7.0

MABA



2.0 g of copper flotation tailings
100%<0.075 mm

90 mL of deionized water

1 or 3 mL of HCl
1.0 N solution

Leaching for 2 hours

HCl 1.0 mol/L solution

Leaching for 22 hours and maintain pH between 2.0 and 2.5

Leaching for 2 hours

Deionized water

Dilution

NaOH solution
(0.10 mol/L)

Titration
Reach pH 8.3

CASE STUDY RESULTS

Static Tests

Samples

Five flotation copper tailings identified as Samples I, II, III, IV, and V, being:

- **Samples I and II** are final flotation tailings from two different copper sulphide ores which the main Cu-bearing mineral being chalcopyrite (**$CuFeS_2$**). These final tailings are a mixture of 90 wt% of rougher tailing and 10 wt% of scavenger tailing.
- **Samples III, IV, and V** are flotation tailings from a different copper sulphide ore which the main Cu-bearing minerals are covellite (**CuS**) and enargite (Cu_3AsS_4). Sample III is the rougher tailing, Sample IV is the scavenger tailing and Sample V is the final tailing, (70 wt% of sample III and 30 wt% of sample IV).
- **Sample I** is from an **industrial operation** in Brazil, **Samples II, III, IV, and V** are from **pilot plant tests**.

Chemical assays

Chemical assays of five copper sulphide flotation tailings

Element/ ID	Sample I	Sample II	Sample III	Sample IV	Sample V
Cu total (wt%)	0.06	0.18	0.05	0.51	0.19
S total (wt%)	0.09	0.22	3.79	26.40	10.30
S sulphide (wt%)	0.07	0.09	0.08	**23.57**	**7.87**
K_2O total (wt%)	2.18	0.94	3.37	2.25	3.00
Al_2O_3 total (wt%)	1.71	8.00	9.45	7.53	8.79
CaO total (wt%)	7.58	2.74	0.10	<0.09	0.09
Fe_2O_3 total (wt%)	15.77	29.02	0.98	29.01	9.57
MgO total (%)	4.56	4.50	<0.25	<0.25	<0.25
MnO total (wt%)	<0.07	0.52	<0.07	<0.07	<0.07
P_2O_5 total (wt%)	1.81	0.44	0.12	0.13	<0.12
SiO_2 total (wt%)	48.07	45.73	73.65	35.44	62.31
F total (mg/kg)	1080	1226	416	308	365
Cl total (mg/kg)	6042	685	434	596	445
As total (mg/kg)	<4	10	10	146	65
S sulphide/ S total mass ratio	0.80	0.40	0.02	0.89	0.76
K_2O+CaO+MgO (wt%)	**14.32**	**8.18**	<3.50	<3.50	<3.50

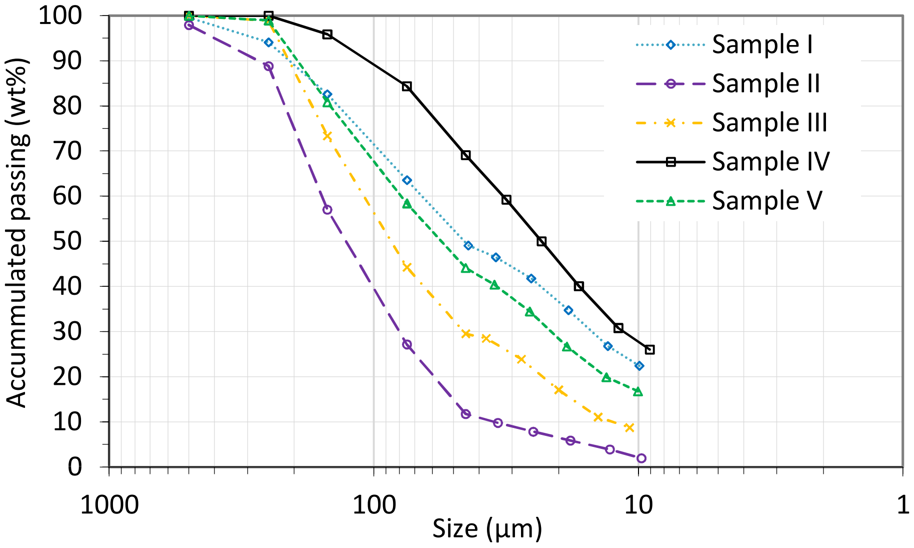
CASE STUDY RESULTS

Static Tests

Size Distribution

Size distribution of samples (accumulated passing, wt%)

Element/ ID	Sample I	Sample II	Sample III	Sample IV	Sample V
500	100	100	100	100	100
250	94	89	99	100	99
150	83	57	73	96	81
75	64	27	44	84	58
45	49	12	30	69	44
35	46	10	29	59	40
25	42	8	24	50	35
18	35	6	17	40	27
13	27	4	11	31	20
9	22	2	9	26	17
<9	0	0	0	0	0
P_{50} (µm)	46	132	90	23	57
P_{80} (µm)	**140**	**222**	**176**	**66**	**147**



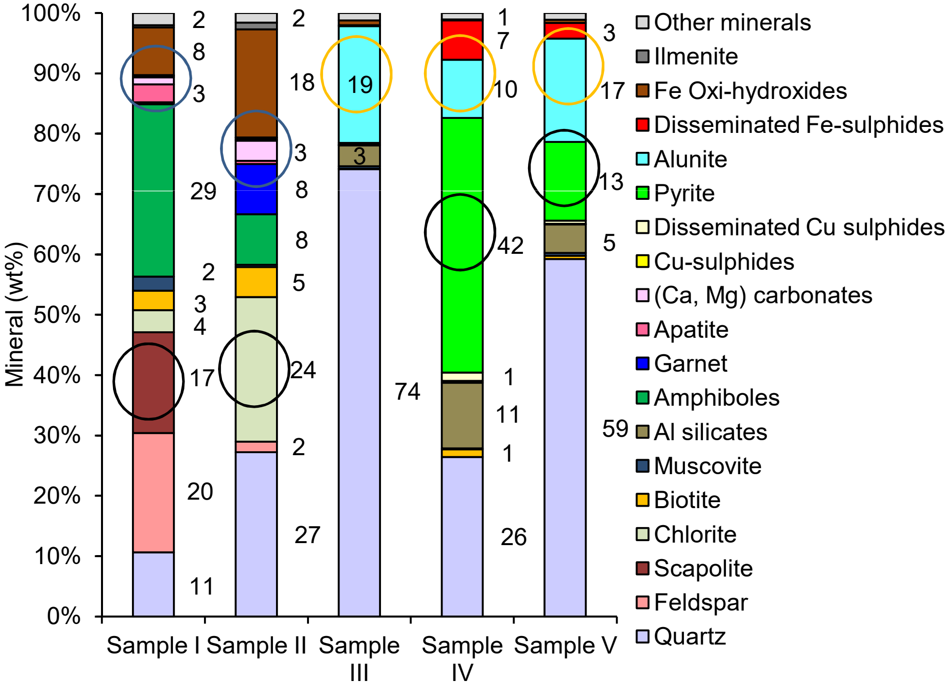
Size distribution of copper sulphide flotation tailings

Sample IV was the finest and sample II was the coarsest with 80 wt% of particles (P_{80}) below 66 and 222 µm, respectively. The samples I, III, and V presented intermediate size distributions, with P_{80} of 140, 176, and 147 µm, respectively. The particle size is an important parameter because it impacts the kinetics of metals dissolution.

CASE STUDY RESULTS

Static Tests

Mineralogy



- ❖ Samples I and II present the most complex mineral assemblage, both have many Fe-Al silicates and Fe oxi-hydroxides.
- ❖ The main minerals in sample I are amphiboles, feldspar, scapolite, quartz, and Fe oxi-hydroxides, totalizing 84 wt% of the total mass.
- ❖ Sample II has quartz, chlorite, Fe oxi-hydroxides, amphiboles, and garnet, which correspond to 86 wt% of the total mass.
- ❖ Basically, sample III is composed of quartz and alunite, representing 93 wt% of the total mass.
- ❖ Sample IV contains pyrite, quartz, aluminum silicates, alunite, and disseminated Fe-sulphides, which together are 96 wt% of the total mass.
- ❖ The main minerals in sample V are quartz, pyrite, and alunite, composing 89 wt% of the total mass.
- ❖ No pyrite in Samples I and II, only 0.3 wt% of pyrite in Sample III.

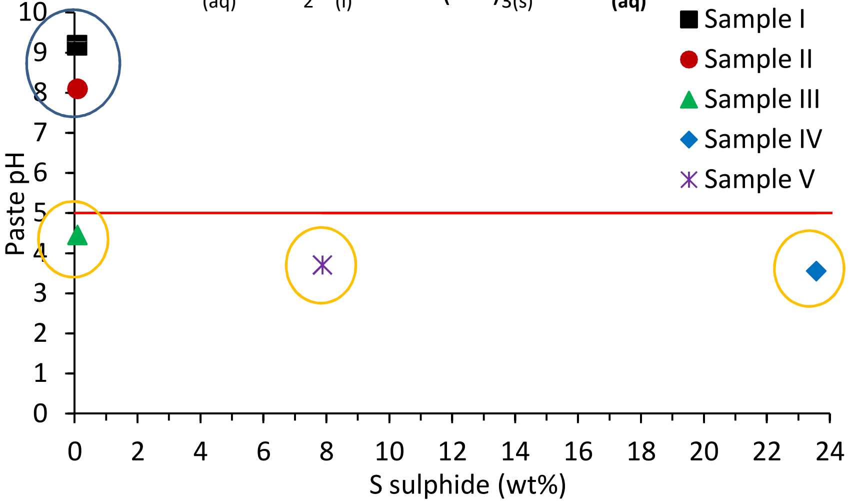
CASE STUDY RESULTS

Static Tests

Paste pH

$(K,Ca_{0.5})Al_3(SO_4)_2(OH)_6(s) \rightarrow K^+_{(aq)} + 0.5\ Ca^{2+}_{(aq)} + 2SO_4^{2-}{}_{(aq)} + \mathbf{3Al^{3+}_{(aq)}} + 6OH^-_{(aq)}$

$3Al^{3+}_{(aq)} + 9H_2O_{(l)} \rightarrow 3Al(OH)_{3(s)} + \mathbf{9H^+_{(aq)}}$



Paste pH versus S sulphide grades for samples

Paste pH of five copper sulphide flotation tailings

Parameter	Sample I	Sample II	Sample III	Sample IV	Sample V
Sample mass (g)	10.00	10.04	10.03	10.07	10.03
Deionized water mass (g)	3.29	3.25	2.51	2.45	2.42
Mass ratio (sample/deionized water)	3.0	3.1	4.0	4.1	4.1
Paste pH	9.19	8.10	4.46	3.56	3.71

- pH of deionized water of 6.48.
- The lowest paste pH was obtained for samples III, IV, and V.
- The low paste pH seems to be due to the presence of alunite in their compositions, being 19.6 wt% in sample III, 9.6 wt% in sample IV, and 17.1 wt% in sample V. The high alunite content in sample III seem to be the reason for the low Paste pH.

$CaCO_{3(s)} + H_2O_{(l)} \rightarrow Ca^{2+}_{(aq)} + HCO_3^-{}_{(aq)} + OH^-_{(aq)}$

CASE STUDY RESULTS

Static Tests

NAG pH

NAG pH of five copper sulphide flotation tailings

Parameter	Sample I	Sample II	Sample III	Sample IV	Sample V
NAG pH	**8.15**	**8.18**	**5.30**	Not possible to measure	Not possible to measure

- High pyrite content in samples IV and V, which are 42.2 wt% and 13.0 wt% of pyrite, respectively. It was not possible to measure the NAG pH of these samples.
- The oxygen released from hydrogen peroxide oxidizes the pyrite. As the reaction is exothermic, heat and gas were released, causing the solution to overflow from the flask;
- Chalcopyrite and covellite can also be oxidized;
- The lowest NAG pH obtained with sample III can be explained by the presence of pyrite (~0.3 wt%), which was oxidized, generating H^+ ions, and lowering the pH.
- Additionally, the absence of calcium carbonate in sample III does not allow the neutralization of its acidity with the addition of hydrogen peroxide.

$$H_2O_{2(l)} \rightarrow 1/2O_{2(g)} + H_2O_{(l)}$$

$$FeS_{2(s)} + 3.75O_{2(g)} + 3.50H_2O_{(l)} \rightarrow Fe(OH)_{3(s)} + 2SO_4^{2-}{}_{(aq)} + 4H^+{}_{(aq)} + \text{heat}$$

$$H_2O_{(l)} + \text{heat} \rightarrow \mathbf{H_2O_{(g)}}$$

$$CuS_{(s)} + 2O_{2(g)} \rightarrow Cu^{2+}{}_{(aq)} + SO_4^{2-}{}_{(aq)}$$

High formation of gases Samples IV and V

CASE STUDY RESULTS

Static Tests

MABA

MABA results of five copper sulphide flotation tailings

ID	**S as sulphide (wt%)**	**AP (kg $CaCO_3$/ t sample)**	**NP (kg $CaCO_3$/t sample)**
Sample I	0.07	2.31	59.76
Sample II	0.09	2.71	34.39
Sample III	0.08	2.50	16.26
Sample IV	23.57	736.43	26.95
Sample V	7.87	245.95	46.00

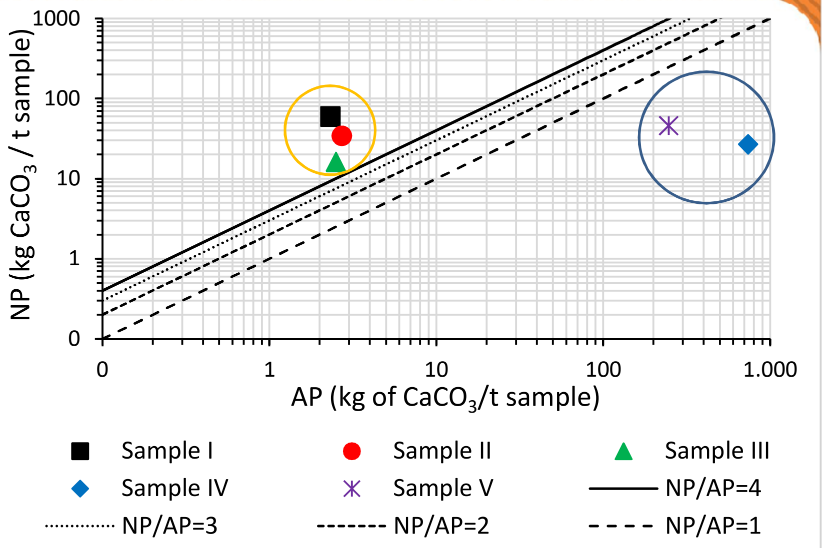


Figure 7. NP versus AP for five copper flotation tailings

$$CaCO_{3(s)} + H_2SO_{4(aq)} \rightarrow CaSO_{4(s)} + CO_{2(g)} + H_2O_{(l)}$$

$$NaOH_{(l)} + HCl_{(l)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$$

$$CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(aq)} + CO_{2(g)} + H_2O_{(l)}$$

According to the MABA tests results, only samples IV and V present acid drainage potential since these two samples show NP/AP mass ratios lower than 1. The main reason for these low NP/AP mass ratios is the respective high AP, being approximately 736 kg $CaCO_3$/t for sample IV and 246 kg $CaCO_3$/t for sample V.

NAF and **PAF** stand for **Non-Acid Forming** and **Potential Acid Forming**, respectively

CASE STUDY RESULTS

Static Tests

Classification of acid mine drainage (AMD) potential

Table 8. Classification of samples for acid drainage potential

ID	Paste pH (pH<5, acid; pH>7, neutral	NAG pH (pH<4.5, acid; pH>4.5, no acid)	MABA NPR=(NP/AP) (kg $CaCO_3$/ t sample) (NP/AP<1, acid; NP/AP>4, no acid)	Classification with MABA results
Sample I	9.19	8.15	>4	NAF
Sample II	8.10	8.18	>4	NAF
Sample III	4.46	5.30	>4	NAF
Sample IV	3.56	Not possible to measure	<1	PAF
Sample V	3.71	Not possible to measure	<1	PAF

- Only samples IV and V could be classified as PAF or with a high potential to generate acidity liquor, and certainly with a high amount of metal dissolved.
- According to these results, it is recommended to carry out acid drainage kinetic tests with samples III, IV and V to determine the long-term weathering rates, such as sulphide oxidation, dissolution of neutralizing minerals, trace metal release, under oxygenated conditions, to evaluate lag time to acid generation and to provide reaction rates for geochemical modeling.

CASE STUDY RESULTS

Kinetic Tests

Procedure

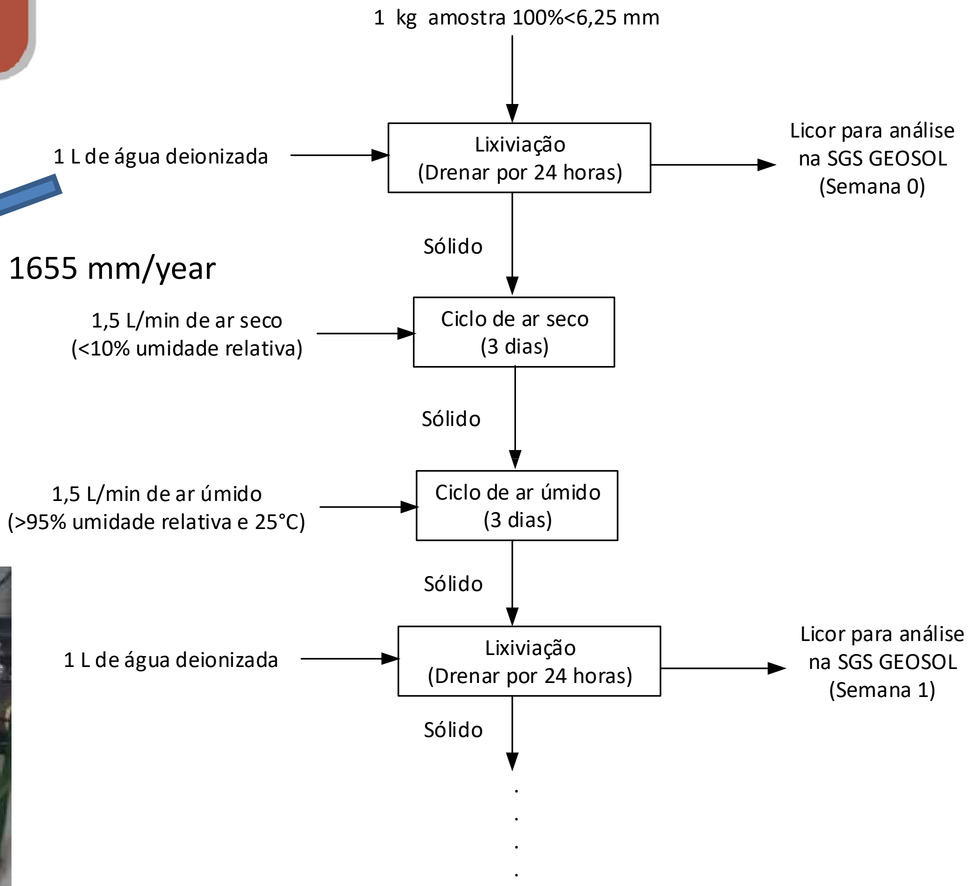
Diameter= 20 cm;

Area=0.0314 m^2

(1 L/week/0.0314 m^2 x 52 weeks/year) ~ 1655 mm/year

Designation: D5744 – 13$^{\varepsilon 1}$

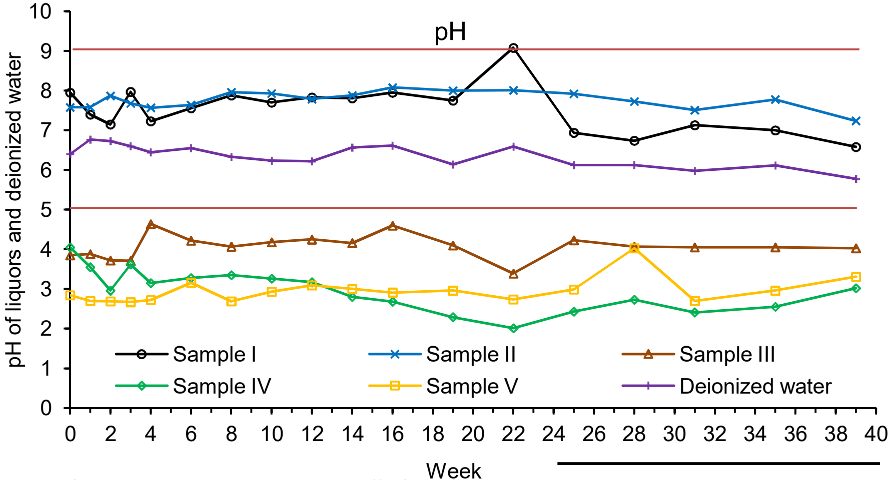
Standard Test Method for Laboratory Weathering of Solid Materials Using a Humidity Cell[1]



Envio dos licores das semana 0, 1, 2, 3, 4, 6, 8, 10, 12, 14, 16, 19, 22, 25, 28, 31, 35, 39, 43, 47 e 51

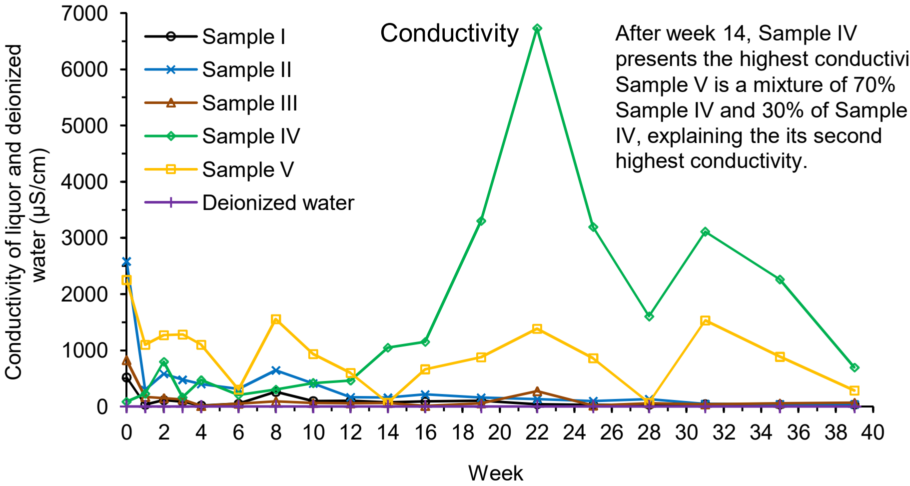
CASE STUDY RESULTS

Kinetic Tests

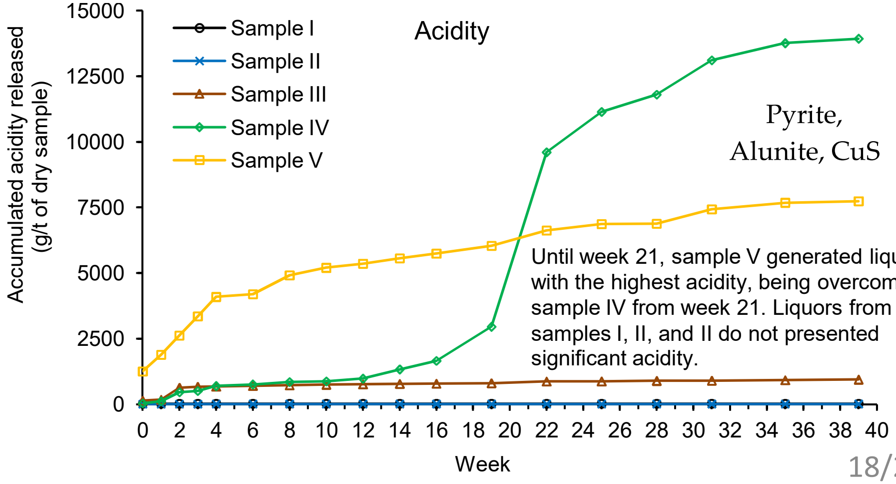


Samples I and II generated an alkaline liquors, with pH above 6.50, whereas the liquors from samples III, IV, and V show a pH below 5.50, which means to be acidity liquors. As expected, no significant variation of pH of deionized water used to leach the samples in each week, which pH was (5.96±0.20), value in the range 5.50 and 6.50.

ID	NAG pH
Sample I	8.15
Sample II	8.18
Sample III	5.30
Sample IV	Not
Sample V	Not



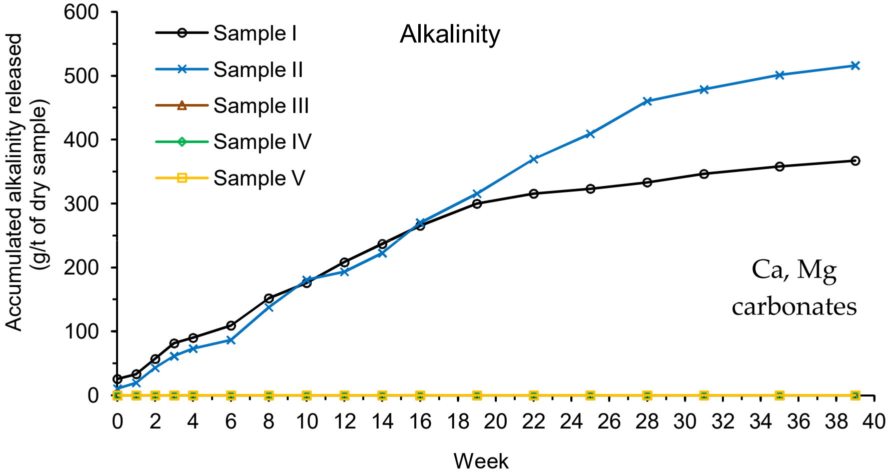
After week 14, Sample IV presents the highest conductivity. Sample V is a mixture of 70% Sample IV and 30% of Sample IV, explaining the its second highest conductivity.



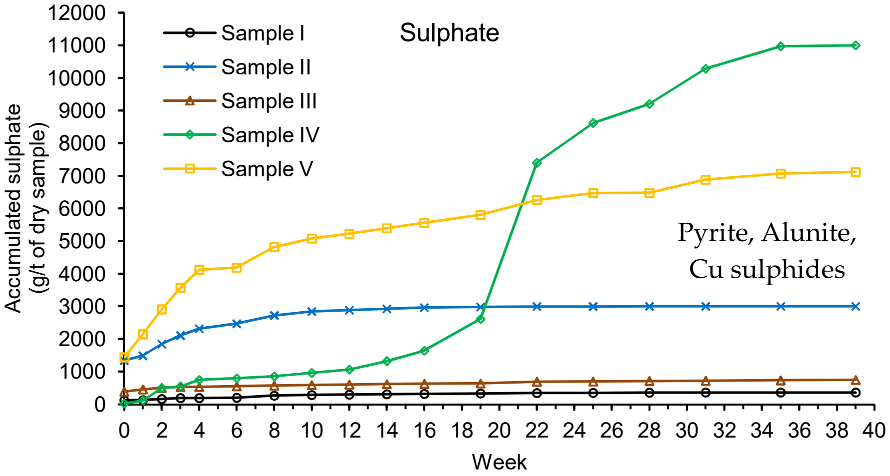
Until week 21, sample V generated liquors with the highest acidity, being overcome by sample IV from week 21. Liquors from samples I, II, and II do not presented significant acidity.

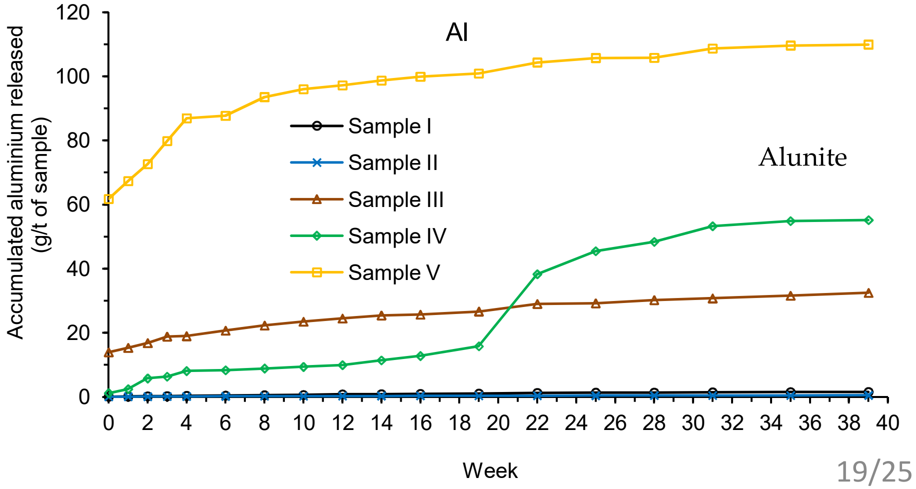
CASE STUDY RESULTS

Kinetic Tests



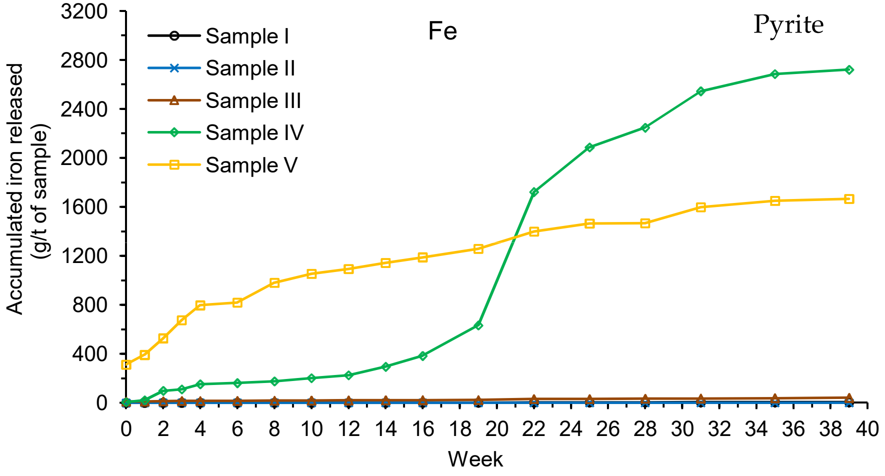
No alkaline liquors with samples III, IV, and V. Same alkalinity for liquors obtained with samples I and II until week 19. The alkalinity of liquor with sample I was overcame by liquor with sample II from week 19.



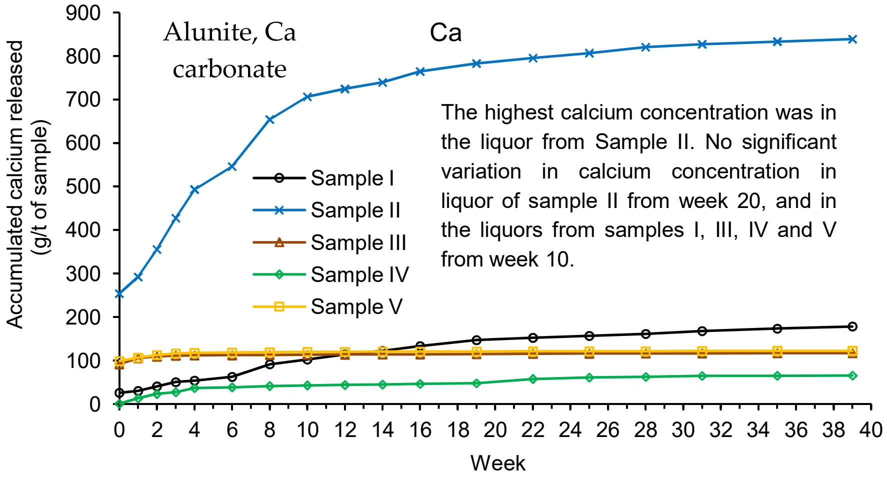


CASE STUDY RESULTS

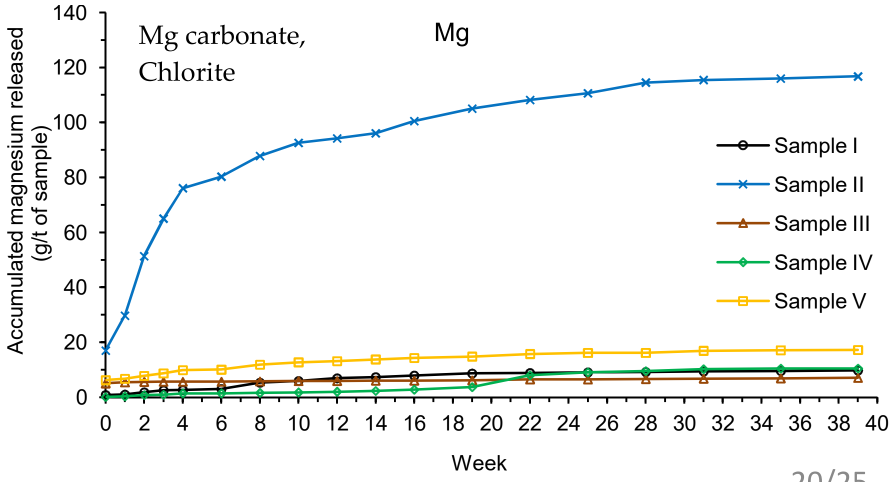
Kinetic Tests



No significant concentration of iron in liquors from samples I, II, and III. The iron concentration in liquor from sample V was overcame by liquor from sample IV in the week 21, same behavior observed for aluminium.

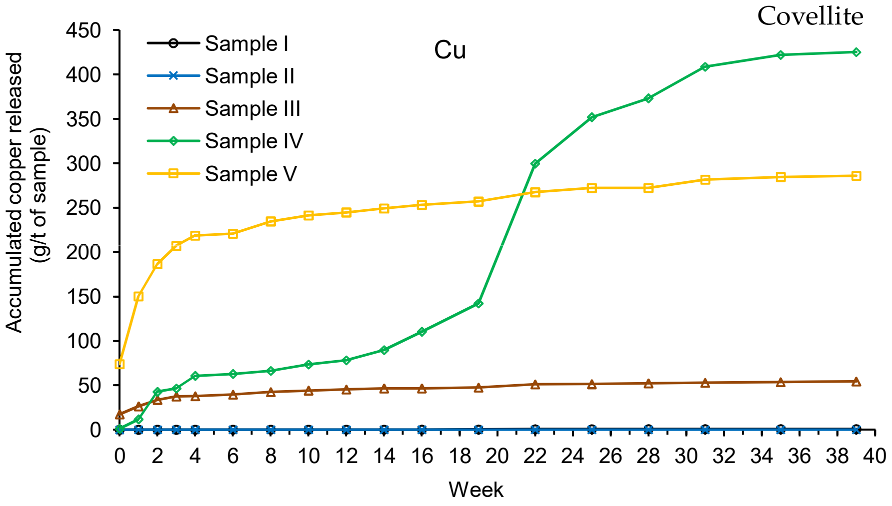


The highest calcium concentration was in the liquor from Sample II. No significant variation in calcium concentration in liquor of sample II from week 20, and in the liquors from samples I, III, IV and V from week 10.

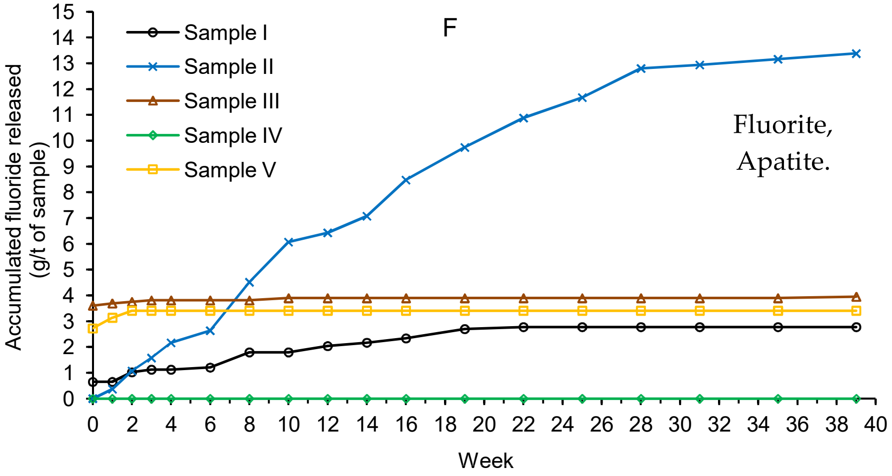


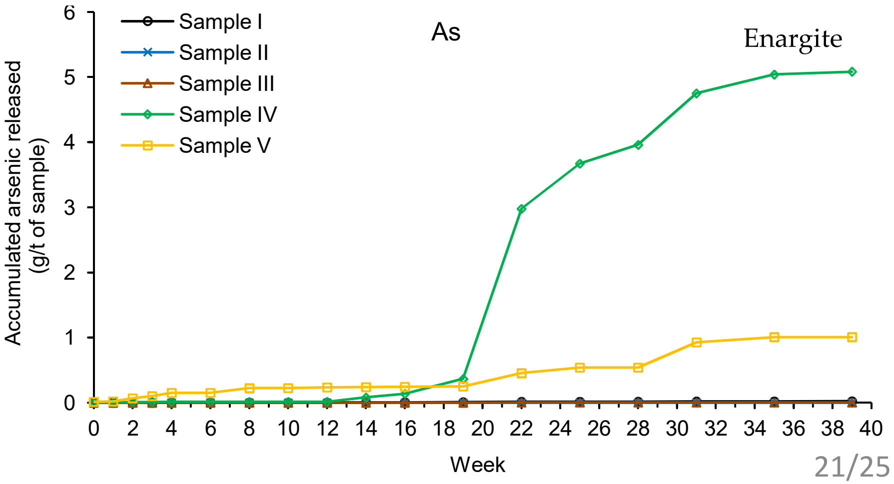
CASE STUDY RESULTS

Kinetic Tests



The highest copper concentration was in the liquor from Sample V. The accumulated copper released from sample V was overcame by sample V in the week 21.

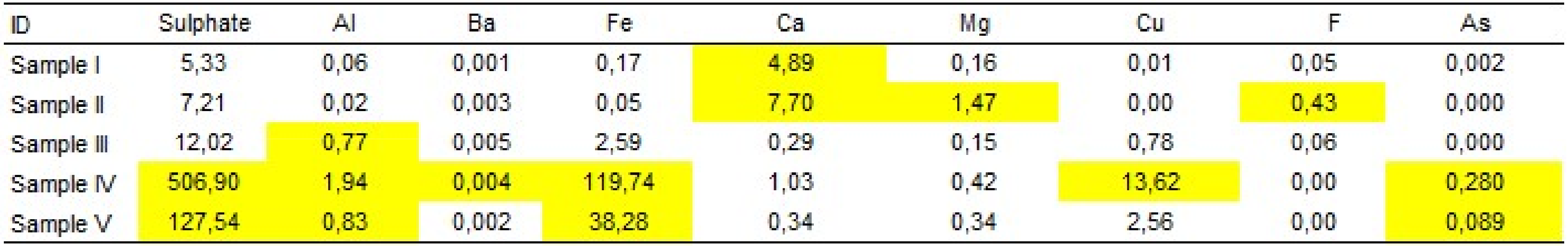




CASE STUDY RESULTS

Kinetic Tests

Metal Released Rate R_M (g/t)



ID	Sulphate	Al	Ba	Fe	Ca	Mg	Cu	F	As
Sample I	5,33	0,06	0,001	0,17	4,89	0,16	0,01	0,05	0,002
Sample II	7,21	0,02	0,003	0,05	7,70	1,47	0,00	0,43	0,000
Sample III	12,02	0,77	0,005	2,59	0,29	0,15	0,78	0,06	0,000
Sample IV	506,90	1,94	0,004	119,74	1,03	0,42	13,62	0,00	0,280
Sample V	127,54	0,83	0,002	38,28	0,34	0,34	2,56	0,00	0,089

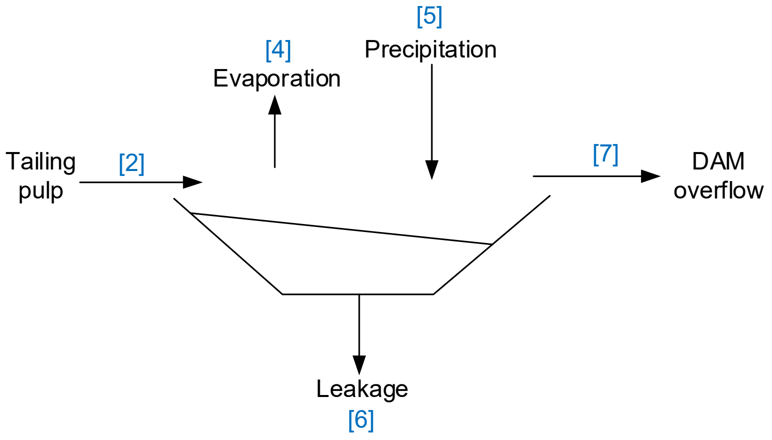
$$\mathbf{R_M = (C_{M\ kinetic\ tests} \times V_L\ ]\ (mg/kg\ or\ g/t)}$$

$C_{M\ kinetic\ tests}$: Mean value from kinetic tests (mg/L);
V_L: Mean Volume of Liquor in Kinetic Tests (L/kg of dry sample).

CASE STUDY RESULTS

Estimation of Liquor Concentration C_M (mg/L)

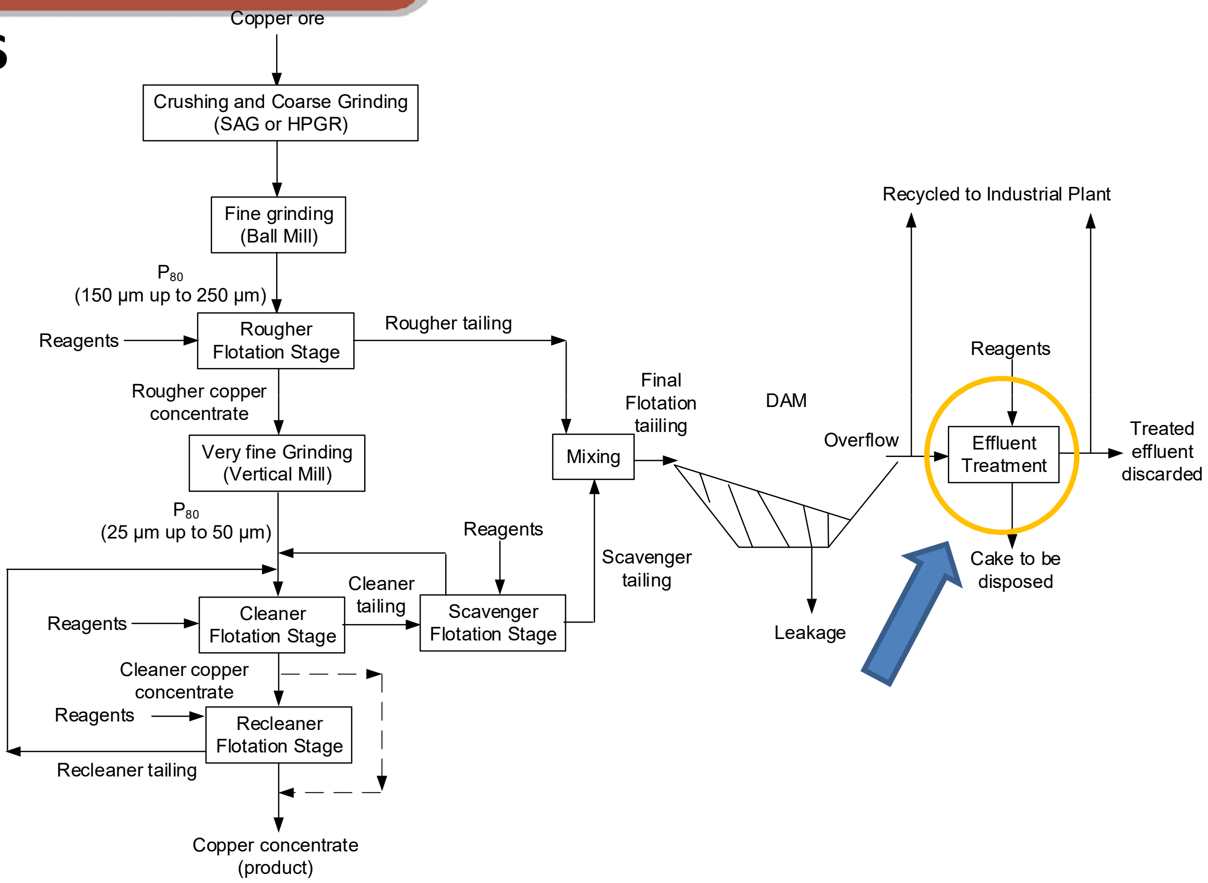
											Liquor Concentration [7]							
	Solids Flow in Tailing Pulp (Mtpy)	Sectional Area DAM (km^2)	Solids content in tailing pulp (%)	Tailing Pulp Mass Flow (Mtpy)	Water Flow in the Tailing Pulp (Mm^3/year)	Evaporated water (Mm^3/year)	Precipitated water (Mm^3/year)	Leakage (Mm^3/year)	Liquid water in the DAM (Mm^3/year)	DAM Overflow (Mm^3/year)	Sulphate (mg/L)	Al (mg/L)	Fe (mg/L)	Ca (mg/L)	Mg (mg/L)	Cu (mg/L)	F (mg/L)	As (mg/L)
Stream	[1]	-	-	[2]	[3]	[4]	[5]	[6]	-	[7]	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Sample I	12,61	13,00	35,00	36,03	23,42	6,50	13,00	0,00	29,92	29,92	2,29	0,02	0,06	1,92	0,06	0,003	0,02	0,001
Sample II	4,85	5,00	35,00	13,86	9,01	2,50	5,00	0,00	11,51	11,51	2,95	0,01	0,02	2,89	0,52	0,001	0,15	0,000
Sample III	24,01	24,75	35,00	68,60	44,59	12,38	24,75	0,00	56,97	56,97	5,02	0,32	1,06	0,12	0,06	0,318	0,02	0,000
Sample IV	10,29	10,61	35,00	29,40	19,11	5,30	10,61	0,00	24,41	24,41	183,11	0,69	42,55	0,42	0,17	4,755	0,00	0,099
Sample V	34,30	35,36	35,00	98,00	63,70	17,68	35,36	0,00	81,38	81,38	46,47	0,30	13,56	0,12	0,14	0,905	0,00	0,031


[5]
Precipitation
[4]
Evaporation
Tailing pulp
[2]
[7]
DAM overflow
Leakage
[6]

- 35% of solids in pulp (Assumed);
- Evaporation rate: 500 mm/year and Precipitation rate: 1500 mm/year (Assumed);
- [2] = ([1]/35%);
- [3] = [2] – [1];
- [4] = 500 x Sectional Area / 1000;
- [5] = 1500 x Sectional Area /1000;
- [6] = 0, assumed;
- [7] = [3] + [5] – [4] – [6]
- **C_M = (Solids Flow x R_M / [7])**

In red values above 357 CONAMA Brazilian Law Class II

CASE STUDY RESULTS



Copper ore

Crushing and Coarse Grinding (SAG or HPGR)

Fine grinding (Ball Mill)

P_{80} (150 µm up to 250 µm)

Reagents

Rougher Flotation Stage

Rougher tailing

Rougher copper concentrate

Very fine Grinding (Vertical Mill)

P_{80} (25 µm up to 50 µm)

Reagents

Cleaner Flotation Stage

Cleaner tailing

Reagents

Scavenger Flotation Stage

Scavenger tailing

Cleaner copper concentrate

Reagents

Recleaner Flotation Stage

Recleaner tailing

Copper concentrate (product)

Mixing

Final Flotation tailing

DAM

Leakage

Overflow

Recycled to Industrial Plant

Reagents

Effluent Treatment

Treated effluent discarded

Cake to be disposed

THANK YOU

Ruberlan Silva, PhD, Chemical Engineer

Vale S.A., Mineral Development Centre (CDM), Brazil.

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