



Original Article

Effect of pretreatment prior to leaching on a chalcopyrite mineral in acid media using NaCl and KNO₃



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ABSTRACT

Chalcopyrite is the most abundant copper ore mined in Chile. Hydrometallurgical plants are currently changing to concentration by flotation-matte smelting deposits when oxide minerals run out and chalcopyrite appears in deposits. The change from hydrometallurgical processing to flotation is mainly dependent on whether comminution costs can be absorbed given the copper grade. It is important to develop alternative technologies to work profitably with low-grade copper sulphide ores. One alternative that has been recently studied is the pretreatment of low copper grade sulphide minerals, especially chalcopyrite, to improve leaching efficiency. The curing time, as pretreatment, improves dissolution kinetics and shortens leaching time. This study used a pure sample of chalcopyrite mineral with 28.5% copper. Chalcocite (copper sulphate) represented 9% of total copper in the sample. The effect of curing time as a function of copper extraction prior to leaching was evaluated using different concentrations of sodium chloride (NaCl), potassium nitrate (KNO₃) and sulphuric acid (H₂SO₄). A 23% copper dissolution was obtained prior to leaching using 25 kg/t NaCl, 15 kg/t H₂SO₄ and 15 days of curing time. The ANOVA analysis reported that curing time was the most important variable (56.4 and 54.7% of contribution) in tests with NaCl and KNO₃. According to the results, KNO₃ does not have a significant effect on copper extraction prior to leaching.

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1. Introduction

Mining is extremely important in Chile's economic, social and cultural development. As Chile transitions from a being developing economy to a developed one, mining plays a key role

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in sustaining the economy, minimizing environment impacts and promoting social growth [1]. One of the most used techniques at present for the recovery of various metallic species such as Zn, Cu, Pb, etc. is by flotation [2,3]. Like all metal recovery techniques, it is possible to find advanced research in this field, such as the modification of surfaces for the flotation of oxidized minerals [2,4].

Currently, copper mining in Chile faces multiple challenges that condition copper production. One of the main challenges is the treatment of refractory copper minerals with the conventional acid leaching, such as black copper oxides [5] and low-grade sulphide minerals, mainly chalcopyrite (CuFeS_2) [6]. Currently, Chile is the world's leading copper producer [7], generating 5.83 Mt in 2018 being the Antofagasta Region one of the most important mining areas in the world [8,9]. According to Cochilco [10], copper production (in Chile) by hydrometallurgical processing will decrease from 28.8% in 2017 to 11.6% by 2029. This is because mining operations are changing to the flotation-matte smelting due to the appearance of primary copper sulphides (mainly chalcopyrite). The major issue with continuing use of hydrometallurgy to treat sulphide minerals is that these minerals are refractory to conventional leaching and have slow dissolution kinetics [11]. Several alternatives have been proposed to treat copper sulphide ores, as for example by using chloride [12–14] or nitrate media [15,16]. Regarding chloride media, chloride leads to dissolve copper sulphides, since it increases the anodic current, forming oxidized complexes with Cu^{2+} and forming a porous layer instead of the passivating layer formed in the dissolution of sulphide minerals [17,18]. The passivating layer inhibits the mineral contact with the leaching solution, thus reducing the dissolution rate [19]. According to Nicol et al. [20], many investigations have studied the composition of this layer. These authors indicated that the indicated layer is formed by a metal-deficient copper-rich polysulphide, as a result of a solid-state transformation of the chalcopyrite surface during the reaction. The composition of this layer is still under investigation [6,20].

Although there is extensive literature on the dissolution of copper sulphides, and the different leaching media that have been proposed, there has been dedicated less attention to leaching pretreatments and how they affect the leaching efficiency [21]. There has been more research recently on the effect of pretreatment on sulphide minerals, mainly in chloride media [13,22,23]. Velásquez-Yévenes and Quezada-Reyes [13] indicated that this pretreatment improves the dissolution of copper from an industrial mineral, whose the main contribution of copper is chalcopyrite. The authors proposed the use of an extensive curing time (between 30 and 100 days) to obtain copper extraction of 42% in leaching columns using intermittent irrigation. Similar conditions are proposed for the treatment of an industrial mineral whose the main contribution of copper is chalcocite and covellite [22]. In other studies, such as that developed by Cerda et al. [23], a maximum of 93% copper dissolution was obtained when the ore (chalcopyrite 1.2 wt%) was treated with 90 kg Cl/t ore, with 40 days of curing time at 50 °C in leaching flasks. A study developed by Hernández et al. [24] used NaCl and NaNO_3 in the pretreatment and subsequent leaching of an industrial mineral whose main copper contribution was chalcopyrite. In this case, a maximum

copper extraction of 58.6% was obtained, with the addition of 23.3 kg NaNO_3 /t, 19.8 kg NaCl/t and 30 days of curing time at 45 °C.

The curing pretreatment is beneficial because of the agglomeration and curing time of the mineral prior to leaching. The agglomeration stage contributes to heap permeability, keeping fine particles attached to coarser ones. This increases the mineral/solution contact, thus improving copper extraction [25,26]. Curing can make mineral species easier to dissolve in the leaching stage, which increases overall efficiency and shortens processing time [22]. According to Dhawan et al. [25], a curing treatment generates a homogeneous acid distribution in the mineral bed, as well as inhibiting aluminum-silicate minerals.

Several studies explain the benefit of pretreatment in sulphide minerals through leaching efficiency, but not previously. This paper presents the results of a study on the effect of chalcopyrite pretreatment in chloride and nitrated media prior to leaching through moderate conditions, at room temperature. A chalcopyrite mineral was used, which was characterized by several techniques. Curing time efficiency was evaluated by measuring the percentage of dissolved copper prior to leaching. The results were also analyzed by an analysis variance (ANOVA), which indicated the optimal combination of parameters. The effect of interaction among the parameters was not considered in this analysis. The predictive results of the model support this assumption, although it could be further confirmed by conducting additional experiments.

2. Experimental

2.1. Materials and procedures

Natural chalcopyrite mineral was obtained by manual collection from an operating plant in Antofagasta, Chile. The sample was primarily crushed by a jaw crusher, followed by a secondary and tertiary use of cone crusher, then milled in a ball mill and finally screened in a size fraction of $-38 + 25 \mu\text{m}$.

The chemical composition of the screened sample was determined by inductively coupled plasma-optical emission spectroscopy (ICP-OES – Optima 8300, Perkin Elmer). Mineralogical data was obtained by X-ray diffraction (XRD) analysis using a diffractometer (PANalytical X'Pert PRO MPD Alpha1), operating at $4-100^\circ 2\theta$, 45 kV, 40 mA, $K\alpha$ 1.54 Å, step size 0.017° , and a time per step of 150 s. X-ray diffraction analysis and crystalline phase identification were interpreted using the software X'pert HighScore Plus v.3.0e. Qemscan analysis was performed using a Model Zeiss EVO Series, with Bruker AXS XFlash 4010 detectors and Software iDiscover 5.3.2.501. Additionally, a reflection optical microscope (Zeiss, Axiovert 100, Milan, Italy) was used. Finally, morphological characterization was performed using scanning electron microscopy (SEM – JEOL J-7100F, Tokyo, Japan), operated at 20 kV under high vacuum conditions (Emitech K-950X) with a coupled EDS microanalysis system (Oxford Instruments INCA). Mineral samples were metallized with a thin layer of carbon to improve their conductivity.

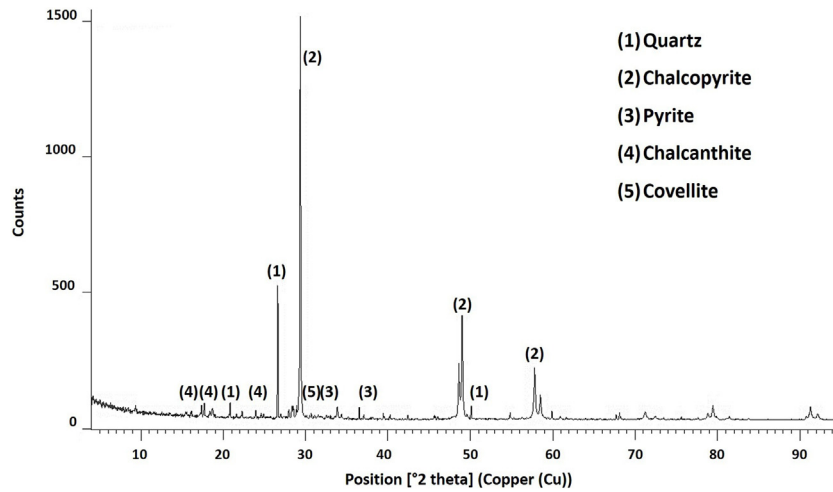


Fig. 1 – X-ray diffraction pattern of the initial sample.

Table 1 – Parameters and levels studied in the experiments with NaCl in acid media.

Parameters		Levels			
		1	2	3	4
A	Curing time (days)	0	5	10	15
B	H ₂ SO ₄ (kg/t)	0	5	10	15
C	NaCl (kg/t)	0	5	10	15

Table 2 – Parameters and levels studied in the experiments with KNO₃ in acid media.

Parameters		Levels			
		1	2	3	4
A	Curing time (days)	0	5	10	15
B	H ₂ SO ₄ (kg/t)	0	5	10	15
C	KNO ₃ (kg/t)	0	5	10	15

2.2. Experimental design

In this study, the parameters under study were curing time and the concentration of H₂SO₄, NaCl and KNO₃, while the response variable was the copper extraction. The Taguchi method is a statistical technique initially designed for improving quality in manufacturing. It has been widely used in engineering design [27,28]. The Taguchi method consists of procedures for system, parameter and tolerance design to obtain a robust process that results in the best product quality [29,30]. The Taguchi method uses an orthogonal arrangement as its core element.

The first case mainly studies the effect of sodium chloride in acid media. In this case, a L₁₆(4³) design was used with three parameters and four levels for each parameter, as shown in Table 1.

The second case studies the effect of potassium nitrate in acid media. In this case, a L₁₆(4³) design was applied with the three parameters and four levels of each parameter, as shown in Table 2.

The R language [31] and the DoE.base experiment design library [32] were used to analyze the results with an analysis of variance (ANOVA) that indicated the optimal parameterization. In order to observe the different effects of uncontrollable factors (noise sources) on this process, the experiments were conducted twice under the same operating conditions. Performance characteristics were carried out by maximizing Eq. (1) [33,34] as shown below:

$$SN_L = -10 \text{Log} \left[\frac{1}{n} \sum_{i=1}^n \frac{1}{Y_i^2} \right] \quad (1)$$

The SN_L response is the performance characteristic that we are seeking to maximize, n is the number of repetitions of an experimental configuration and Y_i is the performance value for the ith experiment. The experiments that represent the optimal operating conditions may not be included in the orthogonal design, in which case the performance values of the optimal conditions can be predicted using the balanced characteristics of the orthogonal arrangement [34]. Thus, an additive linear model was applied, as shown in Eq. (2):

$$Y_i = \mu + X_i + e_i \quad (2)$$

where μ is the general average of the performance value, X_i is the fixed effect of the combination of parameter levels used in the ith experiment and e_i is the random error of the ith experiment.

The order of the experiments was obtained by transferring the parameters to the columns of the orthogonal arrangement L₁₆(4³), chosen according to the experimental plan shown in Tables 1 and 2. The order of the experiments was random in order to avoid additional sources of noise that were not initially considered and that could negatively affect the experiments [33].

The F test evaluated the process parameters and determined if they had significant effects on the performance value. The F value of the process parameters is the ratio between the average of the squared deviations from the mean of the

Table 3 – Main mineralogical composition of the initial sample (mass in %) according to the Qemscan analysis.

Mineral	Mass (%)
Chalcopyrite	73.7
Quartz	16.3
Covellite	1.80
K-Feldspar (orthoclase, anorthoclase)	1.80
Pyrite	1.30
Molybdenite	1.00
Alunite	0.900
Other gangue	2.60
Other Cu minerals	0.600

quadratic error. In general, the higher the F value, the more significant the effect on the performance value due to change in the parameter.

Basic diagnostics were applied to assess the reliability of our linear models and evaluate whether they were appropriate. The graphical analysis of the residuals shows that the shape of the data is acceptable. Therefore, the data can be considered to follow the normality assumption required for linear models. Moreover, in both cases, the data does not break the heteroscedasticity assumption of the linear model (i.e., constant variance of the residuals). Finally, using a Bonferroni analysis of the studentized residuals we found no extreme observations that required further analysis. Thus, the use of the linear model is considered appropriate.

2.3. Curing experiments

Pretreatment tests were conducted in this work using 2 g samples of chalcopyrite to determine the appropriate curing time and concentrations of H_2SO_4 , NaCl and KNO_3 (Tables 1 and 2). A solid/liquid ratio of 10/1 (2 g/0.2 mL) was used to wet the samples. Each sample was homogenized (agglomerated) with the solution (dissolved H_2SO_4 , NaCl or KNO_3) and covered to avoid evaporation. The agglomerated sample was allowed to cure at room temperature for 0, 5, 10 and 15 days. Once the curing time was completed, the sample was washed with a diluted solution of sulphuric acid (0.5 g/L) by mechanical agitation using a mechanical stirrer (Heidolph Instruments, RZR 2051, Schwabach, Germany) at 200 rpm, a solid/liquid ratio of 1/100 (2 g/200 mL) at room temperature for 5 min. Liquid samples were filtered (0.2 μm) and the metal concentrations in the filtrate were determined by inductively coupled plasma-optical emission Spectrometry (ICP-OES – Optima 8300, Perkin Elmer).

3. Results and discussion

3.1. Initial sample characterization

The chemical composition of the sample was 28.5% Cu, 22.8% Fe and 29.7% S (main elements). Fig. 1 (X-ray diffractogram) shows that the sample contained mainly chalcopyrite, together with quartz, pyrite and chalcantinite. Table 3 shows the mineralogical composition obtained by Qemscan analysis. The main species was chalcopyrite (73.7%), followed by quartz (16.3%) and covellite (1.80%). According to the image

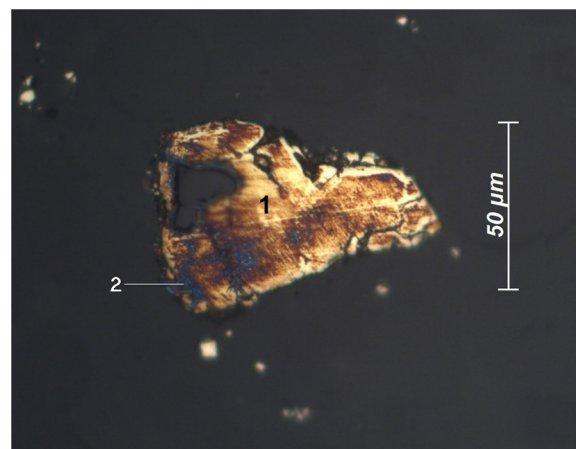


Fig. 2 – Reflected optical microscope image of the initial sample. 1: chalcopyrite; 2: covellite.

Table 4 – Copper extraction (average) in the pretreatment of a chalcopyrite mineral using H_2SO_4 , KNO_3 and curing time.

Curing time (days)	H_2SO_4 (kg/t)	KNO_3 (kg/t)	% Cu extraction (average)
0	0	0	10.27
0	5	5	10.55
0	10	10	10.74
0	15	15	10.86
5	0	5	10.15
5	5	0	10.75
5	10	15	11.40
5	15	10	11.64
10	0	10	11.05
10	5	15	11.64
10	10	0	12.12
10	15	5	12.69
15	0	15	11.11
15	5	10	12.17
15	10	5	12.13
15	15	0	12.44

obtained using a reflected optical microscope, chalcopyrite was also be associated with covellite (Fig. 2). The presence of chalcantinite was also evidenced by SEM analysis (Fig. 3D). SEM analysis showed the majority presence of chalcopyrite, quartz and copper sulphate in the initial sample. Finally, the presence of chalcantinite was measured by washing the sample in water: a 9% copper extraction was obtained.

3.2. Pretreatment and ANOVA analysis

3.2.1. The effect of nitrate in the acid media

Table 4 shows the average of copper extraction (average of duplicate tests) from the pretreatment tests using KNO_3 , H_2SO_4 and different curing days. The effects on the copper extraction were minimal considering that a 9% of copper extraction is associated to chalcantinite and it is a water soluble compound. According to the characterization and mass balance, covellite represented 4% of total copper. Thus, a copper extraction over 13% guarantees solubility of the

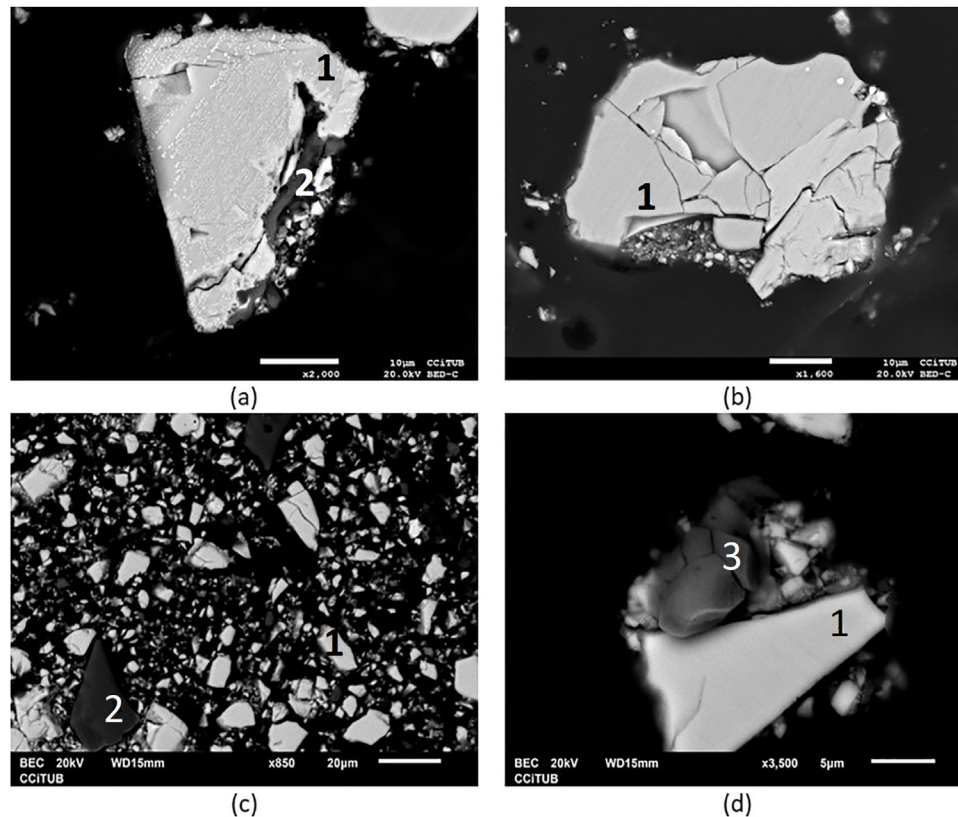


Fig. 3 – SEM image of the initial sample. 1: chalcopyrite; 2: quartz; 3: copper sulphate (chalcantinite).

chalcopyrite product from the pretreatment. Under these conditions, the non-significant effects of the variables are evident. According to [24] reported favorable effects of using NaNO_3 and NaCl in the pretreatment of a copper sulphide mineral. The authors confirmed the study of [35], who concluded that a mixture with high concentrations of sodium chloride and sodium nitrate in an acid media was more effective. However, in the present study, the synergy of the two reagents was not evaluated. There was no significant effect of KNO_3 as an additive in the pretreatment of a chalcopyrite mineral.

Table 5 shows the results of the ANOVA analysis based on the data in Table 4. According to the ANOVA analysis, parameter A (curing time) had the most significant contribution to variation in the Cu extraction (54.66%) with a significant p -value, parameter B (sulphuric acid) had a moderate contribution (35.75%), with a significant p -value and finally, parameter C (KNO_3) had an extremely low contribution (0.61%), with a non-significant p -value. As can be seen, the contributions of A and B are statistically significant according to the p -values (99% confidence level).

To obtain the optimum performance, Eq. (1) is maximized according to the yield value given by Cu dissolution. The degree of influence or effect of the parameters are shown in Fig. 4. Fig. 4A shows that the optimum value is obtained with level 4, which is 15 curing days. Copper extraction increased with curing days [13,22,23]. Note that level 1, which is 0 days, has a much poor performance than the other evaluated levels, and that there is little difference between levels 3 and 4,

which indicates a law of diminishing returns at this point, that is, longer curing times do not significantly increase Cu extraction. Fig. 4B shows that the optimum value was obtained with level 4, which is 15 kg/t of H_2SO_4 , representing an almost linear performance increase for this parameter. Fig. 4C shows that the optimum was obtained with level 3, with 10 kg/t of KNO_3 . Numerical variations are very low compared to the other factors.

The analysis of the results indicates that the optimal configuration is (4, 4, 3), that is, curing days (A): level 4 or 15 days, H_2SO_4 concentration (B): level 4 or 15 kg/t, and KNO_3 concentration (C): level 3 or 10 kg/t. The optimal configuration is not found in the experimental results. Therefore, it is possible that the true optimum is outside the established limits. However, the extractive power of these variables is minor, representing not more than 3% of copper extraction (without considering the dissolution of chalcantinite, which represents 9% of Cu dissolution). According to the linear model, the optimal Cu extraction with this configuration was 12.55%. This test obtained an average copper extraction of 12.93%. Among the configurations in the orthogonal arrangement, (4, 4, 1) obtained the best performance, with a predicted Cu extraction of 12.55% (the same as the theoretical optimum, given that factor C has practically no influence), followed by (3, 4, 2) with 12.45%. Considering that the influence of factor C is not significant according to the ANOVA, it makes sense that low levels such as 1 or 2 can be used. Table 6 shows the details of the experimental and predicted values.

Table 5 – Results of the ANOVA analysis of the parameters for the Cu extraction, with varying concentrations of H₂SO₄ and KNO₃ and curing time (df, degrees of freedom; SSE, sum of squared errors; MSE, mean squared errors).

	Parameters	df	SSE	MSE	F value	Contribution %	p value
A	Curing time (days)	3	10.7	3.566	44.68	54.66	1.578 × 10 ⁻⁹
B	H ₂ SO ₄ (kg/t)	3	6.997	2.332	29.23	35.75	7.391 × 10 ⁻⁸
C	KNO ₃ (kg/t)	3	0.1192	0.0397	0.50	0.61	0.6876
	Error	22	1.756	0.0798			
	Total	31	19.57				

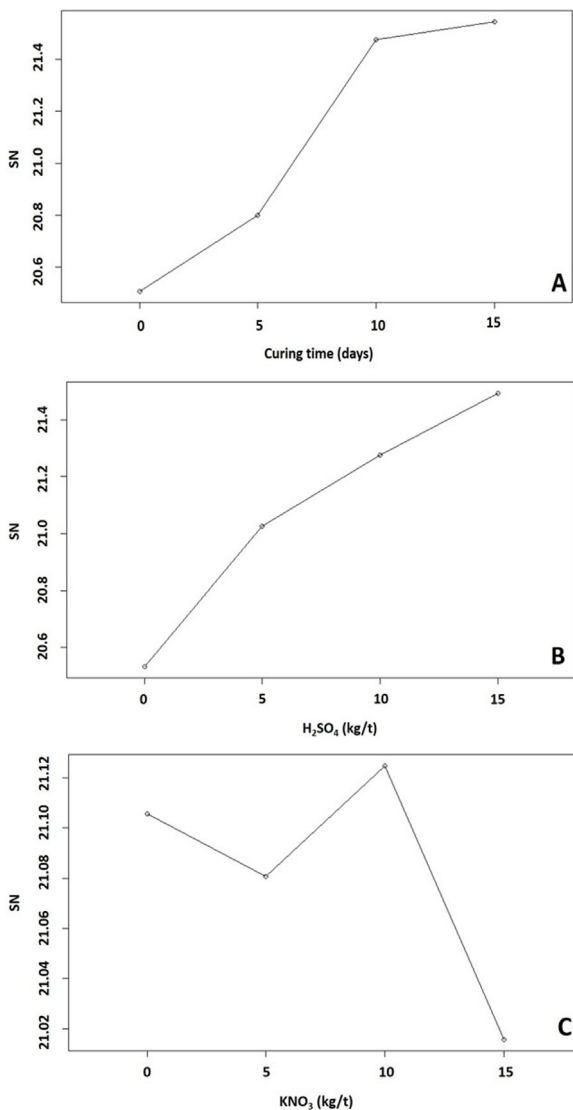


Fig. 4 – Effect of the parameters: curing days (4A), the concentration of sulphuric acid (4B) and concentration of KNO₃ (4C) on the SN.L optimization criterion for Cu extraction prior to leaching.

3.2.2. The effect of chloride in the acid media

Table 7 shows the resulting copper extraction (average of duplicates) with the variables NaCl, H₂SO₄ and curing time. With 0 curing days, the copper extraction was between 10% and 10.82%, which is expected, considering that the sample had 9% copper associated with chalcantite, i.e. between 1%

Table 6 – Experimental results and the values predicted by the linear model given by Equation 2, with varying concentrations of H₂SO₄, and KNO₃ and curing time.

A	B	C	% Cu extraction (average)	Predicted % Cu
1	1	1	10.27	9.930
1	2	2	10.55	10.55
1	3	3	10.74	10.89
1	4	4	10.86	11.05
2	1	2	10.15	10.29
2	2	1	10.75	10.94
2	3	4	11.40	11.12
2	4	3	11.64	11.57
3	1	3	11.05	11.21
3	2	4	11.64	11.69
3	3	1	12.12	12.16
3	4	2	12.69	12.45
4	1	4	11.11	11.14
4	2	3	12.17	11.92
4	3	2	12.13	12.22
4	4	1	12.44	12.55

Table 7 – Copper extraction (average) in the pretreatment of a chalcopyrite mineral using H₂SO₄, NaCl and curing time.

Curing time (days)	H ₂ SO ₄ (kg/t)	NaCl (kg/t)	% Cu extraction (average)
0	0	0	10.27
0	5	5	10.54
0	10	10	10.63
0	15	15	10.82
5	0	5	10.08
5	5	0	10.18
5	10	15	14.71
5	15	10	14.29
10	0	10	14.56
10	5	15	16.08
10	10	0	11.87
10	15	5	16.91
15	0	15	15.95
15	5	10	15.92
15	10	5	15.91
15	15	0	12.58

and 2% copper had been dissolved with pretreatment. The highest copper extraction was obtained with 10 and 15 curing days. In addition, the synergy between NaCl and H₂SO₄ increased copper extraction. Some tests yielded Cu extraction of about 13%, which indicates the reactivity of the chalcopyrite under these conditions. The benefit of using NaCl in pretreatment has been evidenced by previous research [13,23,24]. However, the effect of pretreatment was only evaluated in

Table 8 – Results of the ANOVA analysis of the parameters for the Cu extraction with varying concentrations of H₂SO₄, NaCl and curing times (df, degrees of freedom; SSE, sum of squared errors; MSE, mean squared errors).

	Parameters	df	SSE	MSE	F value	Contribution %	p value
A	Curing time (days)	3	112.4	37.47	22.017	56.36	8.047×10^{-9}
B	H ₂ SO ₄ (kg/t)	3	3.544	1.181	0.6942	1.780	0.5654
C	NaCl (kg/t)	3	46.04	15.35	9.018	23.09	4.3817×10^{-4}
	Error	22	37.44	1.702			
	Total	31	199.4				

terms of leaching efficiency, but not prior, as in this investigation.

According to Table 7, and drawn from the ANOVA analysis, parameter A (curing time) accounted for the major part of variation in the Cu extraction (56.36%), with a significant *p*-value. Parameter B (H₂SO₄ concentration) had an extremely low contribution (1.78%), with a non-significant *p*-value. Finally, parameter C (NaCl concentration) had a moderate contribution (23.09%), with a significant *p*-value. As can be seen in Table 8, most of these contributions are statistically significant, according to the *p*-values obtained (significant A and C at a 99% confidence level).

Fig. 5 shows the degrees of influence or effect of the different parameters. In Fig. 5A, it can be seen that the optimum was obtained at level 4 (15 days), the copper extraction improved with more curing time. Note that level 1, which is 0 days, had a much poorer performance than the other evaluated levels, and that there was little difference between levels 3 and 4, which indicated a law of diminishing returns at this point. Fig. 5B shows that the optimum was obtained at level 4, which is 15 kg/t of H₂SO₄, representing a linear performance increase for this parameter. However, the ANOVA indicated that the influence of factor B was not significant. Fig. 5C also shows that the optimum of NaCl was 15 kg/t. As in the other cases, level 1 with 0 kg/t had a much lower yield.

According to the analysis of the results, the optimal configuration was (4, 4, 4), that is, the following levels of each parameter: curing days (A), level 4 or 15 days; H₂SO₄ concentration (B), level 4 or 15 kg/t, and NaCl concentration (C), level 4 or 15 kg/t. Since the optimal levels were not found in the experimental configuration, there was a possibility that the true optimum was outside the established limits. The configuration (4, 4, 4) was not found in the orthogonal array, so it was not possible to obtain an empirical result for this configuration. However, according to the linear model, the optimal copper extraction with this configuration was 16.72%. The combination (4, 4, 4) was tested, and obtained an average copper extraction of 19.56%. In order to demonstrate the behavior of the mineral outside the studied ranges, tests were carried out in which the concentration of NaCl was increased up to 25 kg/t, this being the saturation point of the solution. The use of 25 kg/t of NaCl, under the conditions evaluated in this study was the maximum allowable according to its solubility in water. Finally, with a combination of 15 curing days, 15 kg/t of sulphuric acid and 25 kg/t of NaCl, a copper extraction of 22.66% was obtained.

Among the configurations in the orthogonal arrangement, (3, 2, 4) had the best performance, with a predicted extraction rate of 16.01%, followed by (4, 1, 4) with 15.79%. Table 9 shows the details of the experimental and predicted Cu extractions.

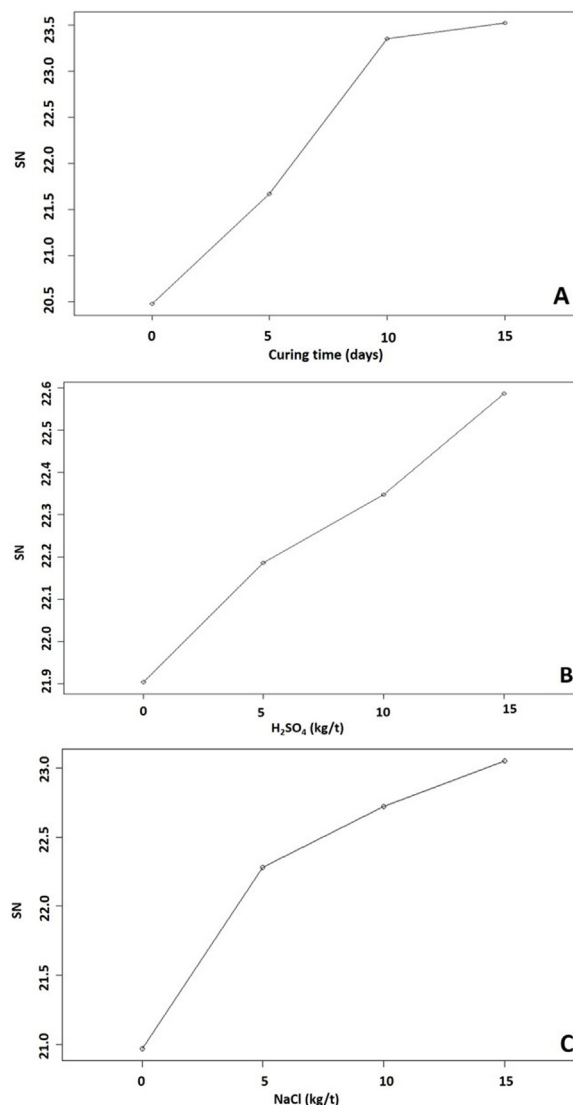


Fig. 5 – Effects of the parameters curing days (5A), the concentration of H₂SO₄ (5B) and concentration of NaCl (5C) on the SN.L optimization criterion for the Cu extraction prior to leaching.

4. Conclusions

The potassium nitrate–sulphuric acid media system (15 kg/t H₂SO₄, 10 kg/t KNO₃ and 15 days of curing time) as a leaching pretreatment resulted in a copper extraction of 12.93%. The ANOVA analysis indicated that this combination of variables

Table 9 – Experimental results and the values predicted by the linear model in Eq. (2), with varying concentrations of H₂SO₄, NaCl and curing times.

A	B	C	% Cu extraction (average)	Predicted % Cu
1	1	1	10.27	8.100
1	2	2	10.54	10.69
1	3	3	10.63	11.28
1	4	4	10.82	12.19
2	1	2	10.09	11.98
2	2	1	10.18	10.31
2	3	4	14.71	13.57
2	4	3	14.29	13.40
3	1	3	14.56	15.01
3	2	4	16.08	16.01
3	3	1	11.88	12.95
3	4	2	16.91	15.45
4	1	4	15.96	15.79
4	2	3	15.92	15.71
4	3	2	15.91	15.32
4	4	1	12.59	13.56

was the most influential combination. The results obtained were consistent with the Cu extraction predicted by the model (12.55%).

The sodium chloride–sulphuric acid media system (15 kg/t H₂SO₄, 15 kg/t NaCl and 15 days of curing time) resulted in a copper extraction of 19.56% prior to leaching. The ANOVA analysis indicated that this combination of variables was the most influential evaluated in this study. However, the Cu extraction differed from that predicted by the model (16.72%), it can be due to the synergy between H₂SO₄ and NaCl.

Curing time is the most influential variable in the pretreatment of a chalcopyrite mineral under the conditions evaluated in this study. According to the ANOVA analysis, its influence was 56.36% in a chloride media and 54.66% with a nitrate media, both with significant *p*-values.

The sodium chloride–sulphuric acid media system (15 kg/t H₂SO₄, 25 kg/t NaCl and 15 days of curing) achieves a copper extraction of 22.66% prior to leaching. In this study, NaCl benefits copper dissolution more than KNO₃ in the pretreatment of a chalcopyrite mineral. KNO₃ does not have a significant effect on copper extraction prior to leaching in the experimental conditions employed.

Conflict of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of Competing Interest

The authors report no declarations of interest.

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