Evaluation Of Variables Through the Plackett-Burman Design in The Flotation Process of Copper Sulphide Minerals from The San Rafael De Belén Deposit

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ABSTRACT

In the present work, a study of the mineralogical characteristics of the copper mineral from the San Rafael de Belén deposit was carried out, in order to investigate and identify significant variables for efficient recovery and achieve an optimal degree of sulfide copper concentrate through foam flotation. The experimental tests showed that with a combination of factors (% solids, pH, collector: Aerofloat 25 and flotation time) a recovery greater than 90% of sulfided copper is achieved. The variable characterization tests used the Plackett-Burman experimental design to evaluate the factors involved in the process. It was found that the variables with the highest incidence are the percentage of solids and dosage of the Aeroflotat-25 collector; Finally, a first-order mathematical model was determined to predict the recovery of the sulfide copper mineral present in the deposit.

Keywords: flotation of minerals; copper sulfides; plakett - burman design

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Evaluación de Variables Mediante el Diseño Plackett-Burman en el Proceso de Flotación de Minerales Sulfurados de Cobre del Yacimiento San Rafael de Belén

RESUMEN

En el presente trabajo se realizó un estudio de las características mineralógicas del mineral de cobre proveniente del yacimiento San Rafael de Belén, con el fin de investigar e identificar variables significativas para la recuperación eficiente y lograr un grado óptimo de concentrado de cobre sulfurado mediante flotación con espuma. Las pruebas experimentales demostraron que con una combinación de factores (% de sólidos, pH, colector: Aerofloat 25 y tiempo de flotación) se logra una recuperación superior al 90% del cobre sulfurado. Las pruebas de caracterización de variables utilizaron el diseño experimental Plackett-Burman para evaluar los factores involucrados en el proceso. Se encontró que las variables de mayor incidencia son el porcentaje de sólidos y dosificación del colector Aeroflotat-25; Finalmente, se determinó un modelo matemático de primer orden para predecir la recuperación del mineral de cobre sulfurado presente en el depósito.

Palabras clave: flotación de minerales; sulfuros de cobre; plakett - diseño birmano

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INTRODUCTION

The San Rafael de Belén project is located between the Eastern and Western Cordilleras, on the Cuchucho and Ninasaylle hills, in the Kunturkanki district, Canas province of the Cusco region, outcrops from 4200 to 4500 meters above sea level. It consists of 400 hectares, where important copper deposits emerge in the form of: Chalcosine (Cu_2S), Bornite (Cu_5FeS_4), Malachite ($CuCO_3.Cu(OH)_2$), Chrysocolla ($CuSiO_3.2H_2O$), Cuprite (Cu_2O), Siderite ($FeCO_3$ and Limonite ($2Fe_2O_3.3H_2O$), so it is proposed to concentrate these valuable species through foam flotation.

The flotation concentration process allows for the recovery of valuable mineralogical species from sulfide minerals. The main variables involved in the performance of the process are the circuit configurations, the type of mineral, granulometry, type of water, chemical family of the collector, height of the foam mattress, air flow (m^3/h), stator and rotor configuration, as well as the % solids of the pulp. On the other hand, the flotation of copper sulfides involves the use of reagents, generally the use of lime as a surface modifier, xanthate as a primary collector, the use of a secondary collector that includes mixtures such as dithiophosphate, thionocarbamate or mercaptan, to In the case of foaming agents, methyl isobutyl carbonyl, pine oil, Dowfroth 250, Dowfroth 1012 (glycols) can be used normally used in the flotation of porphyry copper (Bray 1999; Chia, 1984; Taggar 1968). "At an industrial level, the increase of 1% to 2% in recovery is economically profitable, so the concept of optimization of the production process is one of the main tools to establish the increase in income and reduction of costs, which allows a decision-making process. decision from the technical-economic point of view" (Ayres 1999).

The Plakett - Burman statistical analysis technique applied to mineral processing by flotation allows the study of various factors and their main repercussions on the system, thus making process optimization possible.

There are Plackett – Burman models for experiments in multiples of 4. The experiences of these arrangements are defined in the first row and from these the set of experimental arrangements is constructed, rotating each previous column cyclically. These designs allow adjusting a first-order empirical mathematical model for the variables studied that influence the process in a significant way.

METHODOLOGY

In the present work, a certain number of experimental tests have been carried out, with the purpose of choosing the concentration of the appropriate reagents that will be used in the evaluation of the variables proposed for the flotation of study minerals.

For the purposes of this research project, the variables: % solids, pH, Aerofloat-25 collector dosage and flotation time are selected for experimental evaluation. This fact does not invalidate the possibility of using the number of variables that is deemed necessary. Therefore, the other process variables will be kept constant during the experimentation. The variables with their respective levels for the design are shown in table 1.

Table 1. Levels of the variables

VARIABLES	Level (-)	Level (+)
Z1 : % solids	25	30
Z2 : pH	8	9
Z3 : Aerofloat 25 collector dosaje (g/TM)	10	20
Z4 : Floating time (min)	6	8

Table 2 presents the conditions and dosage of the reagents used for the experimental design.

Table 2: Conditions and dosage of reagents for design tests

	PROOF							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Flotation Cell (cc)	2000	2000	2000	2000	2000	2000	2000	2000
% Solids (%)	**30**	**30**	**30**	**25**	**30**	**25**	**25**	**25**
Pulp Density (g/l)	1243	1243	1243	1195	1243	1195	1195	1195
Dry Sample Weight (g)	745.95	745.95	745.95	597.40	745.95	597.40	597.40	597.4
Water (cc)	1741	1741	1741	1792	1741	1792	1792	1792
pH (Na_2CO_3)	**9**	**9**	**8**	**9**	**8**	**8**	**9**	**8**
Depressant (Na_2SiO_3)	1.9	1.9	1.9	1.5	1.9	1.5	1.5	1.5
Manifold - Z - 11 (cc)	0.6	0.6	0.6	0.5	0.6	0.5	0.5	0.5
Aerofloat 25 (cc)	**0.1**	**0.3**	**0.1**	**0.1**	**0.3**	**0.2**	**0.2**	**0.1**
Foaming agent: Aerofoth-70 (drops)	7	7	7	6	7	6	6	6
Conditioning RPM	1500	1500	1500	1500	1500	1500	1500	1500
Float RPM	1500	1500	1500	1500	1500	1500	1500	150
Conditioning Time	5	5	5	5	5	5	5	5
Float Time	**6**	**8**	**8**	**8**	**6**	**8**	**6**	**6**

The planning of the experimental design (with a single test at the extremes) indicates the values of the variables on a natural scale (Zj), to construct the design matrix for the present research work, a vector of size n is taken (n = 7) and the remaining vectors of the experimental design matrix are generated that will be used for the evaluation of the variables of the flotation process of the study mineral through the optimization design (Plackett - Burman).

The analysis of variance leads us to the appreciation of the significance of the effects in the experimental design, that is, through this analysis we observe the variables: % solids, pH, Aerofloat -25 collector dosage and flotation time, whether they are really important in the investigated range, for which Table 3 presents the data conditioning for the identification of the significant variables.

Table 3: Placket-Burman design for the flotation process

Run	**FACTOR LEVEL**							**Y (Recovery)**
	A	**B**	**C**	**D**	**E**	**F**	**G**	
	Solids (%)	**Float time (min)**	**Fake factor 1**	**Fake factor 2**	**Aerofloat-25 collector dosing (g/TM)**	**Fake factor 3**	**pH**	
1	30	6	-1	1	10	1	9	86,3
2	30	8	-1	-1	20	-1	9	90,3
3	30	8	1	-1	10	1	8	84,9
4	25	8	1	1	10	-1	9	83,5
5	30	6	1	1	20	-1	8	85,8
6	25	8	-1	1	20	1	8	84,3
7	25	6	1	-1	20	1	9	84,1
8	25	6	-1	-1	10	-1	8	80,9

Table 3 shows the variables selected in the preliminary tests for the experimental evaluation; Therefore, the other factors of the process will remain constant during the experimentation, the variables with their respective levels for the design are shown in table 4.

Table 4: Constant process conditions

STAGE	**PROCESS CONDITIONS**	**AMOUNT**
GRINDING	Dry Sample weight: 100% -10mesh Grinding time	1 kg 20 min
FLOTATATION	Flotation cell(cc) Depressor (Na_2SiO_3) Manifold (Z – 11) Foaming agent: Aerofoth-70 (drops) Conditioning time Conditioning RPM	21 250 g/TM 40 g/TM 30 g/TM 5 min. 1500

Float RPM	1500
Foam removal	Every 10 seconds three paddle strokes

RESULTS AND DISCUSSIONS

This design used allowed us to study four process variables and three fictitious factors, later reducing them to a small group of two, that is, in the initial experimentation k=4 variables are studied in N=8 experimental tests (Figure 1), where N > k (8>4). With these data, the design matrix is constructed (Table No. 3), a vector of size n (n =7) is taken, and the remaining vectors of the matrix are generated with it. The design matrix is completed following the Plackett – Burman matrix generating vectors for N=8.

Figure 1: Pareto diagram showing operating variables and dummy variables.

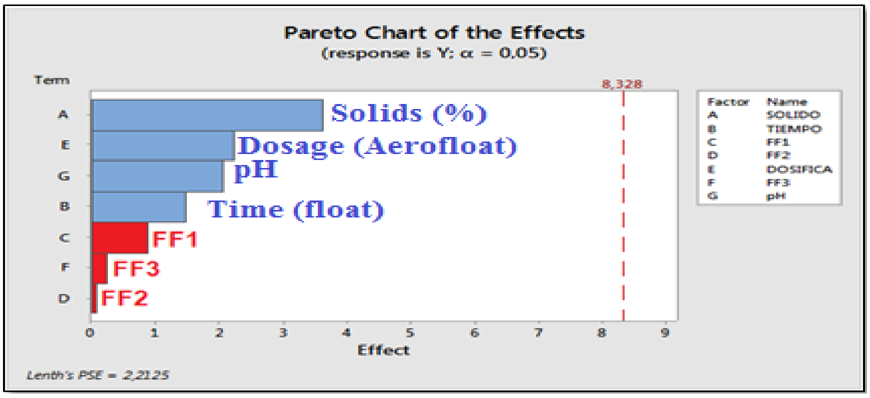
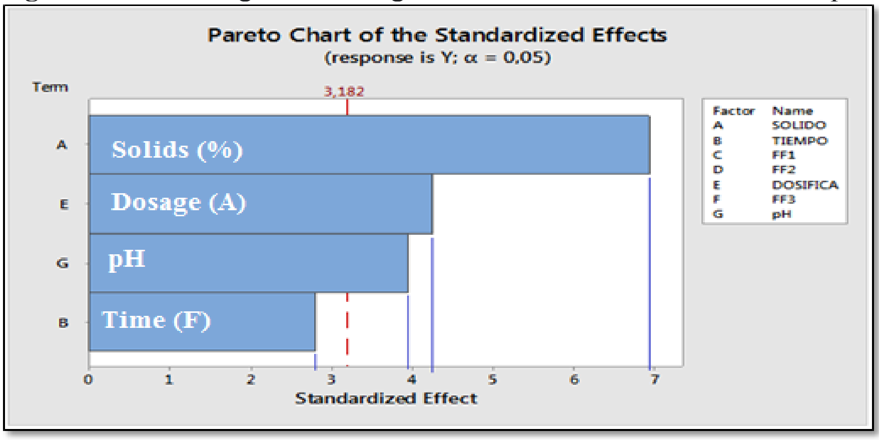


Figure 1 shows the effect of the evaluated variables and we observe that the effect of the percentage of solids is very significant with respect to the recovery of copper minerals, the variables dosage of the aerofloat-25 collector and pH are also important in the recovery of the minerals. copper minerals, however, the flotation time does not have much significance.

Figure 2: Pareto diagram showing the standardized effect of the four operating variables.



The Pareto diagram shown in Figure 2, allows to graphically show the importance of each of the selected variables of the flotation process of sulfide copper minerals, reiterating the importance of the variables % solid, dosage with collector: Aerofloat-25 and pH, have a high priority in the recovery of copper minerals, which are valid by the analysis of variance in table 5; but the floating time is not as important as the recovery effect.

Table 5: Analysis of Variance

SOURCE	DF	ADJ SS	ADJ MS	F-VALUE	P-VALUE
Model	4	49,145	12,2862	22,42	0,014
Linear	4	49,145	12,2862	22,42	0,014
SOLID	1	26,281	26,2813	47,97	0,006
TIME	1	4,351	4,3513	7,94	0,067
DOSAGE	1	9,901	9,9012	18,07	0,024
pH	1	8,611	8,6112	15,72	0,029
Mistake	3	1,644	0,5479		
Total	7	50,789			

Model Summary

S = 1,22423

R-sq = 88,20%

R-sq(adj) = 79,34%

R-sq(pred) = 52,78%

The regression equation in uncoded units for this experimental design is given by:

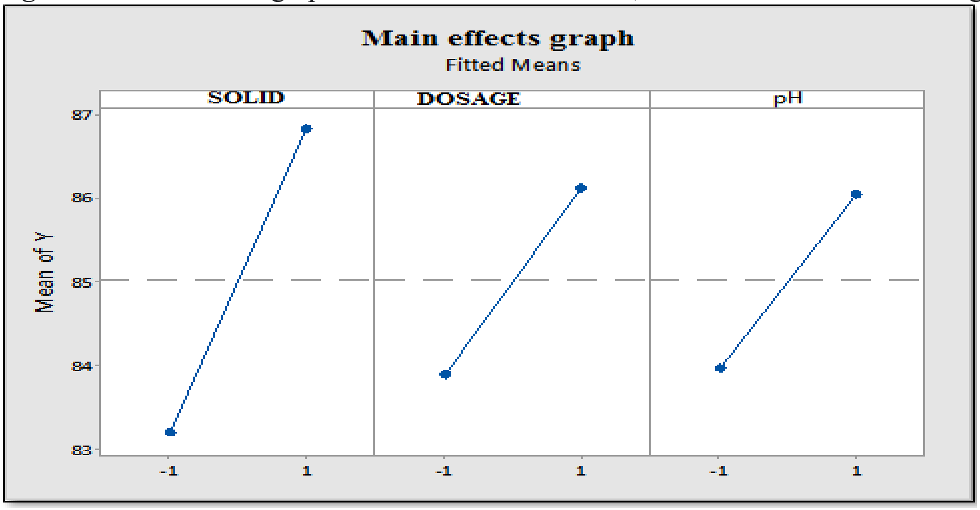
Y = 85,013 + 1,813 SOLID + 1,112 DOSAGE + 1,037 pH. The regression coefficients are positive and in accordance with table No. 6, whose p-value values indicate that the equation constitutes a model for the use of intermediate calculations and corresponding forecasts, and is supported when R-sq = 88.20%. The advantage of this model is that it allows us an ease of interpretation that in this case is ascending and perfectly adjusted to the experimental data.

Table 6: Coded Coefficients

TERM	EFFECT	COEF SE	COEF	T-VALUE	p-VALUE	VIF
Constant		85,01	0,433	196,41	0,000	
SOLID	3,625	1,813	0,433	4,19	0,14	1,00
DOSAGE	2,225	1,112	0,433	2,57	0,62	1,00
pH	2,075	1,037	0,433	2,40	0,75	1,00

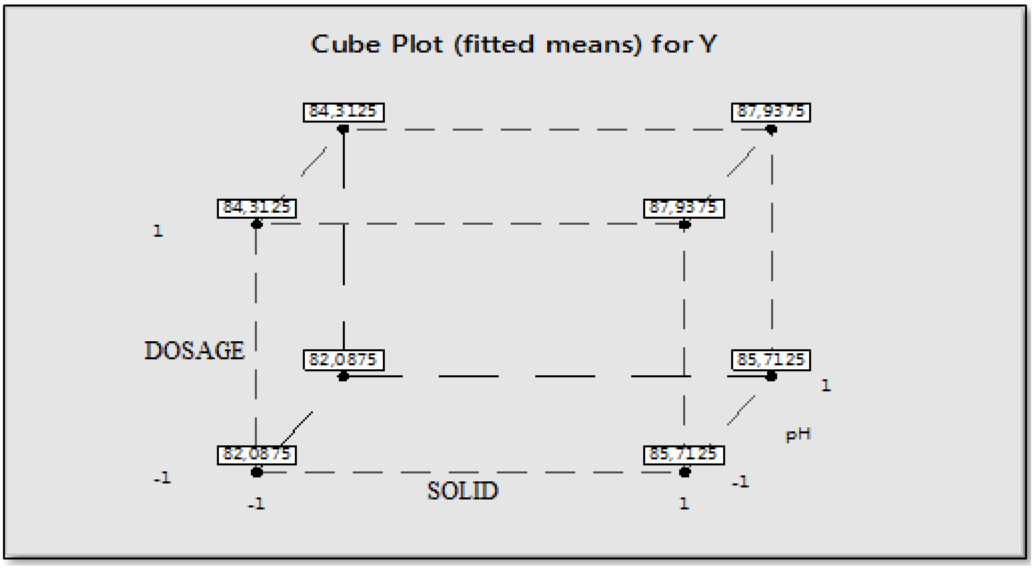
The analysis of variance is a useful tool in statistical inference, it was applied to test the significance of the effects of the variables of the flotation process of sulfide copper minerals, the analysis has allowed us to find that the most significant variables are the % of solids, Aerofloat-25 collector dosage and pH within the investigated range.

Figure 3: Main effects graph of the variables % solids, Aerofloat-25 collector dosage and pH.



Once the conditions of the operating variables have been established, Figure 3 shows the effect that the most significant variables will produce, which are the % of solids, Aerofloat-25 collector dosage and pH on the recovery of copper sulfide minerals in the flotation process. In this case the effects are positive for the process within the studied interval. It is observed that the % solids shows a greater effect.

Figure 4: Cube plot for recovery performance in the flotation process of sulfide copper ores.



The experimental design applied to the recovery of sulfide copper minerals allowed us to identify the variables that truly increase the efficiency of the process, observing in Figure 4, eight experimental points corresponding to a cube which adequately predict the recovery of sulfide copper minerals. The model indicates three independent factors each at two levels, with eight combinations.

CONCLUSIONS

Of the flotation variables for copper sulfide minerals studied that showed the best results were: % solids, Aerofloat-25 collector dosage and pH.

The recoveries and average grades of sulfided copper are considered efficient and commercial, which are:

Reccovery (Cu) = 87.9%

Concentrate law (Cu) = 43.5%

Tailing law (Cu) = 0.4%

The experimental design determined that the mathematical model for the estimated recovery on a natural scale is represented by the following equation:

Y = 85,013 + 1,813 SOLID + 1,112 DOSAGE + 1,037 pH.

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