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Mathematical Modeling for Enhancement Heap Leaching Of D.M.S Tailings for the Recovering Copper and Cobalt: Using Taguchi Method and Analysis Variance.

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***Abstract**: The analytical method of Taguchi was carried out for interpreting leaching results obtained from overall feed of Cu-Co tailings in order to determine the optimal operatory conditions using mathematical model. The orthogonal matrix L25 (5^3) (OA, 3 factors with 5 levels) was performed to evaluate the effects of particle size (+12,5;.+6,3;+2,3;+2,3 +1,7;-1,7 mm), initial acidity (A = 10, 15, 20, 25 and 30 g/L), flow rate (T = 15;17,5;20;22,5 and 25 L/h/m^2) on the metals dissolution rate (Cu and Co).The ANOVA statistical analysis was also used for determining the different interactions between monitored parameters. The experimental results of copper and cobalt dissolutions have showed that under optimal conditions (-1.7mm, 30g/L, 25L/h/m^2) for copper and cobalt, the yield leaching was respectively 89.1% and 61,35%),particle size is in interaction with acidity for copper leaching while acidity is also in interaction with the cobalt flow rate.*

I. Introduction

It is known that metal concentrates might be provided under a lot of ways however, all operations of volumetric reduction from run-off mine in order to obtain a quiet total liberation of valuable minerals and screening for fine grains separation from the coarse size grains should be carried out correctly. Among the ways, fine grains pass in concentration phase by spiral as well as coarse size grains pass also at the concentration by dense mediums method thus, during the separation, the trace elements will be found on the surface while heavy elements come down in the reactor. That separation shows that it become possible to produce, on one hand , an enriched fraction, (concentrated) and the other side a residue (discharge).It means that operatory conditions play a pivotal role during metal concentration for any techniques or methods employed.(Hachicha et al.,2008; Yuan et al., 2008)however, many parameters are indicated for dissolution rate improvement of discharges. For instance the acidity, the residence time, the particle size, flow rate, the chemical composition and others however, the heap leaching require also a very inflexible optimisation during the processing in order to achieve that purpose, the statistical approach using experimental designs of Taguchi and the variance analysis (ANOVA) will be suggest for monitoring the analysis and interpretating of heap leaching experimental results performed.(Phadke, 1998 et Gursi et al.,2008). It is shown that for any research, design or production, the mathematical modelling must be consider under stakes of robust experimental designs, in the offering to improve product quality, and robust methods allowing result approaches in depth. Both methods are basically oriented from the experimental designs, thus, their contribution which is focused on the performance system (Safarzadeh et al., 2008).This coupled method bore several fields engineering in the industry scale such as for conventional techniques to its alternative as bio-engineering domain and even eventually powder metallurgy called nanotechnology. Thus, it is therefore demonstrated that its application is an evidence for better outcomes between interactions variation, which involve much more advantages such as the test reductions to be carried out. Only a bit of time is required, which might involve thus, the decrease of capital investment cost(Hvalec and Al, 2004 ;Ilyas et al., 2010 ; Dobrzanski et al., 2007 Gopalsamy, 2009).Foregoing, the purpose of this paper is to design the optimisation of heap leaching processing of DMS tailings using the coupled methods of Taguchi and variance analysis (ANOVA).

II. Materials And Methods

The sample was collected as tailings ore coming from the DMS (Density Media separation) concentrator of D.R.Congo, after drying in the oven at 120°C during 2 days followed by grinding operation with 150 kg, which was useful for our tests of heap leaching. And then, after analysis by using ICP the results showed the following chemical composition 2.57 % copper 0, 22 % cobalt, 2,66% of Iron ,0,20% MgO and reveal also that a sharp quantity of silica 65% however, mineralogical analysis has shown oxidized phase with Malachite as the main mineralogical phase of ores followed by heterogenite, chrysocole, dolomite, quartz.

Particle size characterisation has been carried out on a sample from DMS tailings with 150 kilogrammes of course by using series of sieves ranging between ASTM ranging between 12,*5mm and* 1,7mm.The non passing of each sieve were weighed and analyzed chemically just to know the copper, cobalt and iron content in each fraction size.The particle size characterization has shown that our sample DMS tailings contain approximately 38 % of particles of size higher than 12mm, with approximately 29% of particles size higher than 6 mm approximately 7% of particles is less than 1.7 mm. The copper and cobalt chemical analysis from various classes of particle-size shows that copper and cobalt are distributed on all the classes. However a great copper quantity is focused on the fraction +12mm, the most coarse fraction size used with 3,09%.of copper, cobalt 0,15% and iron 2,87% The heap leaching tests were carried out in a first phase by using traditional or classical method called method known unvaried which consisting to keep constant all parameters, by varying only one parameter. From those preliminary tests, the experimental design was chosen at the same time the levels of parameters were drafted.

Calculation of yield leaching

The yield leaching is expressed as a percentage relationship between the weight of metal put in solution and total weight of the same metal contained in the sample before leaching, which is expressed by:

$$\eta(\%) = \frac{(P_1T_1 - P_2T_2)\times 100}{P_1T_1} \quad (1)$$

Calculation of acid consumption

It is the quantity of acid consumed in kilogramme brought back to a ton of ore, it is expressed by:

$$CAT(Kg/t) = \frac{C_3.V_1 - C_4.V_2}{P_1}.1000 \qquad (2)$$

In addition, acid consumption by using copper and cobalt ore in Kg/tonne is given by the following expression:

[Solubilisation Cu in Kg/t × 1,54] + [solubilisation Co in Kg/t × 1,66] (3)

Where :1,54 and 1,66 are equivalents acid of copper and cobalt respectively. The acid Consumption by gangue in ore Kg/tonne is given by the relation: consumption of acid total-consumption of acid by copper and cobalt.

The yield leaching solubilisation

After 8 hours of leaching residence time, solubilisation is given by the expression:

$$\eta_8(\%) = \frac{V_8.C_8}{P_M}.100 \qquad (4)$$

For the 8h as coming : $\eta_{16}(\%) = \frac{V_8.C_8 + V_{16}C_{16}}{P_M}.100$ (6)

We can generalize the formula; thus after N hours we have

$$\eta_n(\%) = \frac{V_8.C_8 + V_{16}.C_{16} + \cdots + V_{n-1}.C_{n-1} + V_n.C_n}{P_M}.100 \qquad (7)$$

Experimental designs: orthogonal table of experimentation

The heap leaching processing is led by several parameters: particle sizes, the permeability, acidity, the flow rate, time and others .For this work, we choose three factors, five levels, each one was retained for this study, mentioned again in table 1 and using heap leaching conditions which were retained on their corresponding levels: ore weight in each column, Height of column; Internal diameter, leaching residence time.

Table 1: Parameters and their levels in quantitative values

Weight of ore 3kg in column Interior diameter 80 cm Height of the column 6.5 cm Residence time 168 hours							
Code of parameters	**Name of Parameters**	**Units**	**levels**				
			1	**2**	**3**	**4**	**5**
A	Particle size	mm	+12.5	6.3	2.3	+1	-1
B	Acidity	g/L	10	15	20	25	30
C	Flow ate	h/m^2	15	17.5	20	22.5	25

Normally, in case of three factors on 5 levels, this would have carried out 5^3=125 tests however; the standardization of orthogonal matrix (table 2) per G Taguchi, 25 tests only will be carried out according to the orthogonal plan L_{25}, mentioned again in table (2).A table of integration of whole numbers of which columns, the factor levels represent. Each line represents a test which is by the way a whole of specific levels of each factor. This matrix is draft since, it is appropriate more for experiments carried out in a disturbed medium, each test is repeated twice under the same conditions and at different times, in order to minimize the noise effect sources like the temperature and moisture in the laboratory at the time to carried out tests, (Safarzadeh, 2007;Safarzadeh*et al.,* 2008) The Taguchi approach uses the function quality loss of to measure the variability of the characteristics of performance around the value the robustness targets.(Demirci et al., 2011;Mohd et al., 2009).The value of the function of loss inside is transformed into ratio Signal-Noise (Signal-Noise ratio:S/N) which is:

$$S/B = 10.\text{Log}\ (L) \qquad (8)$$

Where L is the quality loss and S/B is expressed in dB (decibel).

Tableau 2: L_{25} (Orthogonal array)

N° Tests	Parameters and their levels		
	A	**B**	**C**
1	1	1	1
2	1	2	2
3	1	3	3
4	1	4	4
5	1	5	5
6	2	1	2
7	2	2	3
8	2	3	4
9	2	4	5
10	2	5	1
11	3	1	3
12	3	2	4
13	3	3	5
14	3	4	1
15	3	5	2
16	4	1	4
17	4	2	5
18	4	3	1
19	4	4	2
20	4	5	3
21	5	1	5
22	5	2	1
23	5	3	2
24	5	4	3
25	5	5	4

Considering the different performance characteristics, largest ratio S/B corresponds to better performance. Accordingly to this, the parameter level optimum is that which has largest ratio S/B. The performance characteristics are evaluated by S/BL expressions (Yuan, 2009; Demirci, 2011)The optimum is a maximum (larger-the-better). The following ratio S/B must be used:

$$S/B_L = -10\ log(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_{ij}^2}) \quad (8)$$

Ratio S/B is expressed in **dB** (decibel).

Once we wish to minimize the occurrences of certain undesirable characteristics of the product, the optimum is a minimum (smaller-the-better) we can calculate following ratio S/B:

$$S/BS = \quad S/B_S = -10\ \log_{10}\ (\frac{1}{n}\sum_{i=1}^{n} y_{ij}^2\ )\ (9)$$

Here, N is the treatment number, i.e. the number of tests carried out for a given level. And is the response Y_{ij} to the level y_j. Thus, In experimental designs of Taguchi, the combination corresponding to the optimum conditions for work can not appear among combinations retained during the tests, (Safarzadeh *et al.*, 2008) In such a case, the value of answer or the characteristic corresponding to optimal conditions can be predicted by using the following expression:

$$Y_{opt} = \frac{T}{m} + \left(\bar{A}_i - \frac{T}{m}\right) + \left(\bar{B}_j - \frac{T}{m}\right) + \ldots\ (10)$$

Where m is the total number of tests, T the sum of all the answers of tests and , Bj… the average, answers of level i,j,k…

Variance analysis (ANOVA)

The values of answers presented in experimental designs must be analysed in order to measure the factors influence and the interactions on answer variations. The variance analysis named ANOVA is the only method responding to this aim.(Vivier, 2002).The purpose of variance analysis is to test in absolutely the factor influences on variations of a given answer. Variance analysis will make possible to determine statistically: the most significant parameters, the contribution and the contribution's degree of each factor during dissolution of metals.

III. Results And Discussion

All results of these tests were made by the mathematical modelling the statistical evaluation of Taguchi approach and Variance Analysis (ANOVA). The choice of the levels of studied parameters was made basically according to orientation tests. The results are mentioned again in ***Table 3*** and schematized with Figures 1 and 2. These tests series were carried out by the traditional method of heap leaching Thus, we maintained invariable the following parameters Time = 120 min, Temperature 25°C, we have For each series of tests, the studied parameter was varied according to the levels mentioned in ***Table 3***.

Table 3:Experimental design and experimental results of leaching

N° of tests	Parameters and their levels			yield or reponse			S/B_L	S/B_L
	Particle size	**Acidity**	**Flow rate**	**Cu**	**Co**	**Fe**	**Cu**	**Co**
	mm	(g/l)	$L/h.m^2$	%	%	%	dB	dB
1	12.5	10	15	14	9.15	0.15	11.46128	19.22842
2	12.5	15	17.5	26.7	9.3	0.3	14.26511	19.36966
3	12.5	20	20	37.2	16.5	0.57	15.70543	24.34968
4	12.5	25	22.5	44.6	48	0.98	16.49335	33.62482
5	12.5	30	25	45.1	19.7	1.3	16.54177	25.88932
6	6.3	10	17.5	71	17.8	0.3	18.51258	25.0084
7	6.3	15	20	75	13.2	0.19	18.75061	22.41148
8	6.3	20	22.5	82	15.26	0.47	19.13814	23.67109
9	6.3	25	25	89	19.8	0.84	19.4939	25.9333
10	6.3	30	15	80	36.2	0.69	19.0309	31.17417
11	2.3	10	20	52	15.6	0.88	17.16003	23.86249
12	2.3	15	22.5	75.9	17.85	0.59	18.80242	25.03276
13	2.3	20	25	74.21	21.7	6.7	18.70462	26.72919
14	2.3	25	15	74.4	25.22	0.85	18.71573	28.0349
15	2.3	30	17.5	86.4	40.55	0.79	19.36514	32.15982
16	1.7	10	22.5	81.2	31.98	2 .3	19.09556	30.09757
17	1.7	15	25	74.6	30.6	2.56	18.72739	29.71443
18	1.7	20	15	86.06	37.5	2.4	19.34801	31.48063
19	1.7	25	17.5	88.14	55.9	9.27	19.45173	34.94824
20	1.7	30	20	90.24	78.25	8.16	19.55399	37.86969
21	-1.7	10	25	95.98	60.4	0.49	19.82181	35.62074
22	-1.7	15	15	70.6	49.6	0.26	18.48805	33.90963
23	-1.7	20	17.5	82.88	68.4	5.2	19.1845	36.70112
24	-1.7	25	20	91.73	77.59	2.9	19.62511	37.79612
25	-1.7	30	22.5	98.5	89.51	5.39	19.93436	39.03743

Tableau 4 : Marginal averages by levels of factor for copper solubilisation

Levels	**Parameters**		
	A	**B**	**C**
1	21.6265318	29.2588201	29.3744848
2	37.9189804	33.6968964	33.9590892
3	36.8210036	25.9113921	35.1945495
4	38.4290707	35.7396714	32.2885262
5	38.6859167	36.9563068	36.6245654
Ratio S/B expected under optimal conditions	**A_5=-1.7mm**	**B_5=30g/L**	**C_5=25l/hm^2**
Influence of parameters	17.059	7.6965	7.2505
Interaction between parameters linear Adjustment	3.536x+24.01	1.743x+27.08	1.981x+21.04

Tableau 5 : Marginal averages by factor for cobalt solubilisation

Levels	**Parameters**		
	A	**B**	**C**
1	22.7544561	22.880342	25.1153054
2	24.8139327	23.5824451	24.9866358
3	27.2454965	26.5695118	25.5600202
4	31.8839856	29.9627053	27.460563
5	36.251049	30.7200236	27.6481527
Ratio S/B expected under optimal conditions	**A_5=-1.7mm**	**B_5=30g/L**	**C_5=25l/hm^2**

Effect of parameters	13.4971489	6.83968153	2.53284734
Interaction between parameters Adjustment linear	3.406x+18.37	1.981x+21.04	0.754x+23.89

Tables (4) and (5)shows the marginal averages by level of factors for copper and cobalt solubilisations above which it is possible to determine the levels of parameters which optimize the copper and cobalt solubilisation during leaching process which were carried out in accordance with the experimental design of Taguchi listed in table (3).According to the Taguchi approach, the highest value of functional metric average (S/B) for each parameter is optimum for this one. Our Heap Leaching was taken to evaluate the leaching behaviour of tailings DMS, i.e. criterion SBL (larger the better). In overall view, the calculation of ratio SBL was carried out to maximize the copper dissolution and a weak dissolution other elements (selective leaching).The last columns of the table (3) contain the SBL evaluated for each test. The method of Taguchi analyzes the response of each test and the corresponding change by using the ratio signal-noise (S/B).In the criterion optimization chosen, the SBL, the highest value of the metric functional calculus Signal-Noise (S/B) represent the best yield recovery performance the output signal which is the answer, The tables (4) and (5) give averages of ratio S/B of t factors for each variation level, thus the monitoring factors effects with levels on the statistical performance are very important during copper and cobalt leaching process.

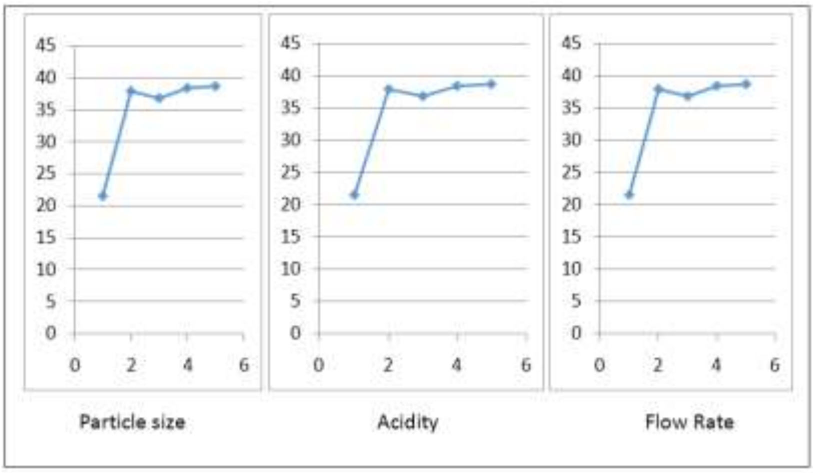

Figure 1:effect of controllable factors with levels on the statistical performance (S/B) for Copper

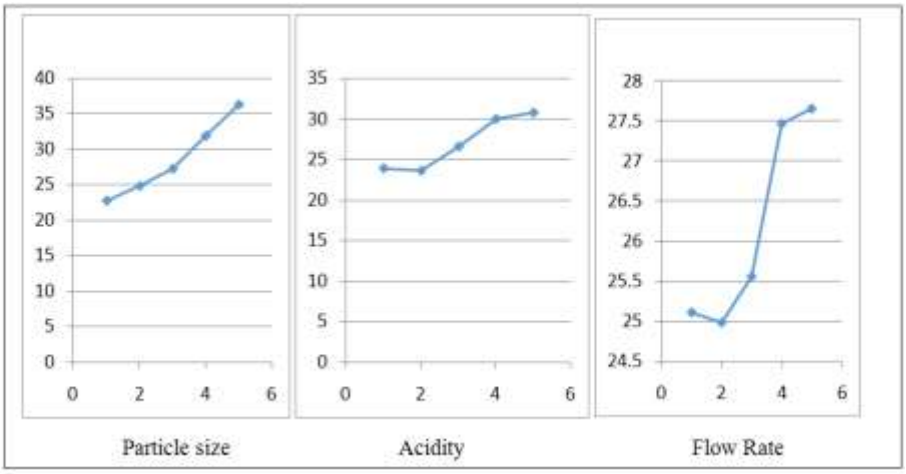

Figure 2: Effect of controllable factors with levels on the statistical performance (S/B) for cobalt

It is arises from Figures (1) and (2) that the optimium for copper and cobalt correspond to the levels A5B5C5(for which letters represent the parameters and the indices represent the levels (Table 3).Values of -17 mm;30g/L and 25 L/h/m^2 corresponding respectively to the particle size (A), acidity (B) and the flow (C) thus, parameters levels awaited under the optimum conditions for copper and cobalt leaching.(Cisternas, et al.,2008)The values obtained in the tables (4) and (5) also make possible to determine the parameter more dominating at time of copper and cobalt dissolution Indeed, in this statistical analysis, the parameter having the most significant effect on the performance of studied system is that of which the difference (Δ) between largest and the smallest value of the metric signal-to-noise functional calculus are large,(Nkulu,2012).This metric represents the difference (Δ) between largest and the smallest value of metric signal-to-noise functional calculus. The analysis accordingly to Taguchi method considers the greatest difference as the most influential parameter. The tableau (3) showed that particle size (=17.059) is the most influential parameter during the copper solubilisation. Tableau (4) shows particle size (Δ=13.497) as the most influential parameter on the cobalt solubilisation. Confirmation of tests Result carried out under the optimal and robust solubilisation condition which specifies also the hydrometallurgical characteristics of leaching process has Showed also that the copper and cobalt solubilisation rate are respectively 89,1 % and 61,35 % and overall consumption of acid is 84,55kg/ts under the optimal conditions. The predictive model applied under optimum conditions for copper and cobalt leaching time showed also respectively the recovery of 98,8% et 62,0 %. Those results confirms the theoretical assertion according to which the results obtained by the statistical method of Taguchi are robust and, therefore insensitive with the disturbing factors and at the same time our approach join the approach carried out by Mellado, et al (2014) on the optimisation of the process of the heap leaching regarding the influence of particle size during solubilisation of metals as shows the figure 3 on the behaviour interaction of parameters .

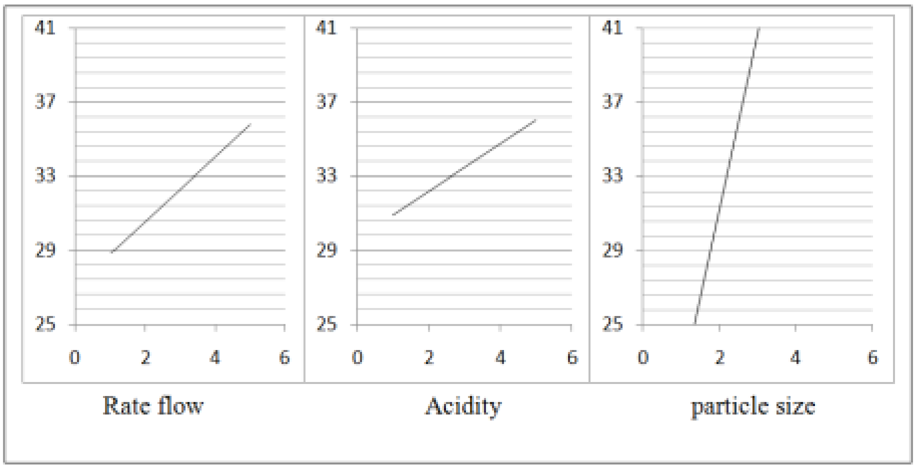

Figure 3: Interaction between controllable factors according to the statistical

In this respect, these various curves (figure 3), we note that the linear line of average relationship related to rate flow is almost parallel to linear the line of acidity average relationship. While the linear line of particle size average relationship is respectively secant with the linear rate flow and lines of acidity average relationship.

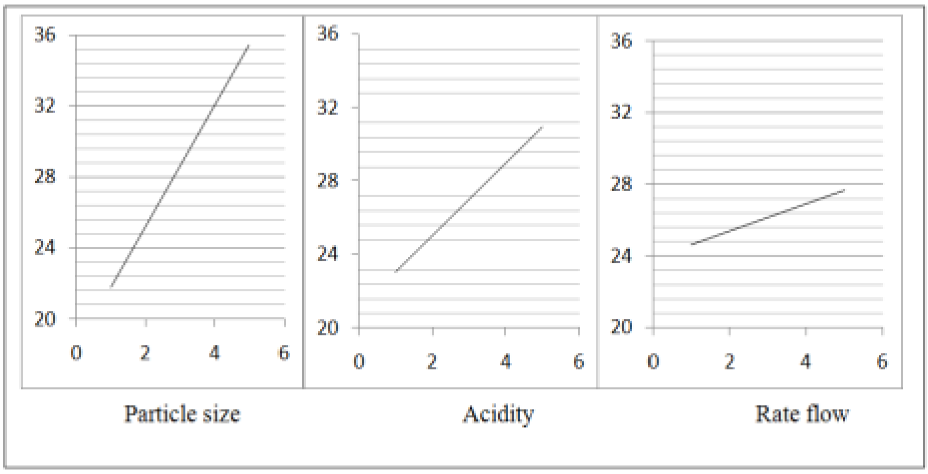

Figure 4: Interaction between controllable factors according to the statistical performance on the leaching of Cobalt

After observation on the various curves (figure 4), we also notice that the linear line of average relationship of particle size is almost parallel to the linear line of average relationship of acidity.While the linear line of average relationship of the flow of watering is respectively secant with the linear lines of average relationship of acidity and particle size.Figures (3) and (4) made it possible to visualize the interdependences called interactions being able to exist between controlled parameters or answers of the studied system.The analysis is made by using the concept of parallelism between the linear lines of average relationship of the various values of the metric signal-to-noise functional calculus (S/B) for each controlled parameter from this concept of parallelism the effect of interaction results. Consequently, the linear lines of average relationship given on the figures (3) and (4) show that certain controlled parameters are in interaction between them. Figure (3) shows that acidity and Particle size are in interaction; the flow and particle size are in interaction (Lizama, H.et al2005)flow and acidity are not in interaction. Particle size is in interaction with the other parameters. In the same way, figure (4) shows that acidity and are not in interaction whereas the interaction between acidity departure and the flow is strong; acidity, the rate flow and particle size are in effective interaction this consideration is also in agreement with the work of Cariaga, E and co-workers.,(2005). An variance analysis (ANOVA) proves to be significant in order to consider the error experimental, and to determine importance of related contribution of various parameters and making possible to make the share due to the real influence of the parameters of randomly which had share. This analysis is also necessary to see whether the controllable parameters are statistically significant. The variance analysis was used to visualize the influence of different factors on the answer and ratio S/B, but also to confirm the results obtained by the Taguchi method using the ratio analysis S/B. the ANOVA was used to determine statistically the most significant parameters and the contribution and contribution's degree of each factor on copper and cobalt rate solubilisation. The results of the ANOVA are given in table (7).

Table 7: Variance analysis for Copper heap leaching

Factors	Sommation de carré	ddl (fz)	Sommation pure	F-Exp(Fz)	Contribution(%)
	0.6890083	4	0.17225208	3.60732922	41.99
Acidity	0.11706557		rejeted		
Flow rate	0.04508017		rejeted		
Tailings	0.95501167	20	0.04775058		58.01
Total	1.18605825	24			100

IV. Conclusion

The variance analysis for leaching in heap of copper confirms the results obtained previously, indeed, in variance analysis, if the factor F (of the test of Fisher) calculated is higher than F critical showed in the table of Fisher for 95%(c' be-with-statement than information obtained has a probability of to be true for around 95% and the 5% are allowed to the errors experimental).This significance is noted on the industrial levels $p <$ 0,05.The value of the Fcrit=2.87 factor showed in the table is lower than the value F calculated for particle size.However for the rate flow and the acidity which have values of F lower than Fcritic, which means that their variance is unimportant vis-a-vis the variance of error and none them has significant effects on the answer (copper solubilization rate).ANOVA, it arises that particle size is the most significant parameter with a contribution of 42% on the dissolution rate of copper. The experimental designs approach, in the methodology of Taguchi, was applied for the method of heap leaching test from DMS Tailing in order to determine optimal operating conditions for copper and cobalt extraction, orthogonal array L25 (5^3) (3 factors with 5 levels) was used to evaluate the effect of Particle size (A = 12.5, 6.3, 2.3, 1.7et -1.7), acidity (10, 15,20,25,30), the rate flow (15, 17.5, 20, 22.5, 25) on copper solubilisation the statistical analysis, ANOVA, also has been used to determine the interactions between the controlled factors. The experimental results metals showed that under the optimal conditions (-1.7 mm, 30g/L and 25 L/h/m^2) the solubilisation rate was respectively 89.1% and of Co 61.35%.Approach of Taguchi, particle size turn out to be the most influential parameter for the copper and cobalt leaching. Particle size was in interaction with acidity for the leaching of copper while acidity is in interaction with the flow for cobalt.Variance Analysis, particle size is again seems the most significant parameter with a contribution of about 42% on the copper yield leaching. (Dixon, D. G., & Hendrix, J. L. 1993a).

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