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Application of Response Surface Methodology for Optimization of Vat Leaching Parameters in Small Scale Mines: Case Study of Tanzania

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Abstract

In this work, the Response Surface Methodology (RSM) was used to study and optimize the vat leaching operating parameters namely as cyanide concentration, slurry pH and particle size. The experimental design was performed with aid of Minitab (version 16) statistical software. The Central Composite Design (CCD) was used to model and analyse the effect of the operating parameters. According to a quadratic model, the optimal conditions for highest gold leach recovery of 83% were found by a cyanide concentration of 950 ppm, slurry pH of 10.5 and particle size of 240 µm. The results are much significant compared with the current gold recovery of between 60 to 70%. The samples were collected at Nyarugusu small scale mines (Geita, Tanzania).

Keywords

RSM, Vat Leaching, CCD, Optimization, Nyarugusu Small Scale Mines

1. Introduction

Gold cyanidation has been used as the principle gold extraction technique since the late 19th Century [1]. Cyanide is universally used as lixiviant because of its relatively low cost and great effectiveness for gold dissolution. Also, despite some concern over the toxicity of cyanide, it can be applied with little risk to health and environment [1].

Generally, gold ores can be classified as “free milling” and “refractory” depending on their response to cyanide leaching [2]. While high gold recoveries (>90%) from free milling ores can be readily achieved, refractory gold ores are often characterized by the low gold extractions (50% - 80%) within a conventional cyanide leaching [3-4]. Gold in secondary deposits results from erosion of gold bearing rock structures, transportation of the eroded material by streams and deposition in placer form. This gold is usually in native and free form and can be easily recovered by conventional cyanidation. In primary (hydrothermal) deposits, magmatic processes have introduced and finely disseminated the gold into sulfide minerals such as pyrite and arsenopyrite, the gold occurs in a submicroscopic form and it is difficult to extract by conventional cyanidation even with fine grinding [5-6]

Currently small scale mines at Nyarugusu, Tanzania use cyanidation technology to recover gold from their ores by vat leaching tanks although the recovery is still low ranging between 60 to 70% despite the high cyanide concentration dosage up to 1200 ppm, particle size range between 300-360 µm, pH ranges between 10.5 to 12.0, leaching time 6-7 days without slurry agitation mechanism. The study focused much on modeling these parameters in relevant to the increase of gold leach recovery. In order to concentrate a metal of interest there must be a mass of material of a defined total volume that will be subjected in metallurgical operations with considerable number of steps and factors affecting the phenomena of the operation [7]. There are many factors affecting leaching process, these includes dissolved oxygen concentration, lixiviant concentration, particle size, agitation rate, temperature and presence of sulphide and other ions in the solution. Many studies have presented that gold extraction increases with increasing cyanide concentration [1, 7-10, 11]. The presence of base metal will consume more cyanide because of the formation of cyano– complexes from these impurities.

However, a high concentration of cyanide may be required due to the competition of other species such as ore containing soluble sulfides [1]. Furthermore, the decrease in base metal concentration in the ore decreases cyanide consumption as well. The use of lower cyanide level can reduce the effluent treatment cost at the plant scale [7, 10]. It has been suggested that oxygen injection, instead of air, provides a high oxygen concentration in the slurry and can achieve high overall gold extraction [11]. However, other researchers found that the oxygen consumption is markedly higher with the use of oxygen gas than air [7]. Many researchers have concluded that increasing the dissolved oxygen concentration increases the rate of dissolution [1, 10-12]. The addition of lime (CaO) is typically used to maintain slurry pH in gold leaching circuit [7, 12].

The gold dissolution rate is expected to reduce with increasing pH since the adsorption of OH^- ion onto gold surface decreases the surface available for cyanide leaching. The study of the effect of particle size on gold conversion found that smaller particle size can improve gold dissolution rate [7-8]. Similar results have been obtained by de Andrade Lima and Hodouin (2005) who presented the residual gold concentration in ore particle as a function of the ore particle size.

However, it was reported that increasing the fraction of finer grinding will also increase cyanide consumption and does not improve gold extraction, probably because residual gold is present in fine occlusions or in solid solution in the mineral matrix [8]. The rate of gold dissolution may decrease with decreasing particle size due to the increased rate of competing and reagent consuming side reactions [1]. Moreover, the grinding costs also increase with the decrease in particle size [12]. Furthermore, the gold dissolution is therefore aimed to increase with increasing temperature [1]. Agitation is one of the important factors in gold leaching since gold dissolution rate depends on the diffusion layer thickness and mixing characteristics of the bulk solution [1]. On other hand when the cyanide to copper ratio at 2.5 is found, the gold leaching rate is low [14]. It was presented that copper cyanide at moderate concentrations has a slightly negative effect on gold dissolution [15]. An adequate free cyanide concentration in the solution can prevent the effect of copper. The ratio of cyanide to copper, approximately 3, is presented to be sufficient to remain high gold leaching rate [1, 14]. Furthermore, gold cyanidation reaction may be described stoichometrically correct by Elsner as shown in equation (1). However it does not completely describe the cathodic reactions associated with the dissolution [1].

$$4Au + 8CN^- + O_2 + 2H_2O = 4Au(CN)_2{}^- + 4OH^- \quad (1)$$

The process is running at sub-optimal setting. The three key factors that control vat leaching are known. Statistical package can be used to find the setting that can increase gold recovery. Response surface methodology is very useful in performing optimization.

2. Experimental

The leaching experiments were conducted in unstirred batch reactor using gold oxide ore as a raw material. These feed materials (oxide ore) for vat leaching in small scale mines are mostly obtained from tailings of sluicing gravity concentration operation.

2.1. Chemical and Statistical Analyses

Fire assay, AAS and X ray fluorescence (XRF) analysis were used to provide information on the metal composition of the feed sample, leach solution and residues from the leach test work. A three factorial experimental design was used to determine the number of experiments and their combination during the experimentation. A total of 20 runs were obtained. The response was gold leach recovery while factors were cyanide concentration, slurry pH and particle size. The gold leach recovery for each run was then calculated using recovery Equation (2). Response surface methodology (RSM) was employed to investigate the variation of gold leach recovery with respect to operating parameters. The accuracy of the model was analyzed using the unbiased estimator δ^2, which is a function of the sum of squared errors of the data produced. The lower this value, the better the approximated RSM model fits the experimental data.

$$R = \left(\frac{f-t}{c-t}\right) * \frac{c}{f} * 100\% \quad (2)$$

Where:
R = Gold leach recovery (%)
f = feed grade (ppm)
t = tailings grade (ppm)
c = concentrate grade/pregnant solution grade (ppm)

2.2. Determination of Operating Conditions

The factors (cyanide concentration, slurry pH and particle size) were the investigated operating conditions. The gold leach recovery (response) was calculated using RSM equations modeled on the experimental results. Table 1 shows the actual setup.

Table 1. *Operating conditions for gold recovery by vat leaching technology*

Current operating conditions			**New modeled operating conditions**	
Factors	MIN	MAX	MIN	MAX
CN (ppm)	800	1200	600	1300
PS(µm)	300	360	150	330
pH	10.5	12	9.5	11.5

3. Results and Discussion

3.1. Gold Recovery

The response surface design yielded a total of 20 runs in a random order with their corresponding gold leach recovery as shown in Fig 1.

A quadratic model was suggested due to its highest order polynomial with significance additional terms and non-aliased model. The model equation based on the actual values for the gold leach recovery is expressed by Equation (3).

$$Y = 82.1595 + 6.9202x_1 - 3.5197x_2 + 0..2183x_3 + 9.7125x_1x_2 + 12.6125x_1x_3 - 12.3125x_2x_3 - 5.001x_1^2 - 0.8551x_2^2 - 9.4995x_3^2 \quad (3)$$

The results of ANOVA and fitness of the quadratic model as well as the effect of individual terms and their interaction on the chosen response (gold recovery) are presented in Fig 2.

Fig 2. shows that out of the three model terms studied, two of them i.e. cyanide concentration (x_1) and slurry pH (x_3) were found to have positive value meaning that increase in their concentrations result to increase in the gold recovery while one model term, particle size (x_2) was found to have negative value meaning that increase in particle size scales down the recovery probably because most of the gold particles are still locked with gangue minerals.

The interaction between cyanide concentration and slurry pH and also cyanide concentration and particle size were found to have positive effect on gold recovery, while the interaction between particle size and slurry pH was found to have negative effect on recovery. The value of the determination coefficient R^2 = 0.9345 means only 6.55% of the total variations are not explained by the model. The value of the adjusted determination coefficient (Adj. R^2 = 0.8755) is also high which supports the model.

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
	StdOrder	RunOrder	PtType	Blocks	CN	PS	pH	P/soln	H. grade	tails	Recovery(%)
1	8	1	1	1	1300.00	330.000	11.5000	0.76	0.450	0.176	79.2
2	5	2	1	1	600.00	150.000	11.5000	1.95	0.357	0.105	74.6
3	10	3	-1	1	1538.63	240.000	10.5000	2.41	0.400	0.091	80.0
4	13	4	-1	1	950.00	240.000	8.8182	1.20	0.400	0.260	44.7
5	4	5	1	1	1300.00	330.000	9.5000	0.76	0.450	0.174	79.5
6	18	6	0	1	950.00	240.000	10.5000	0.76	0.400	0.140	79.7
7	14	7	-1	1	950.00	240.000	12.1818	0.76	0.400	0.220	63.3
8	7	8	1	1	600.00	330.000	11.5000	0.15	0.450	0.730	16.1
9	19	9	0	1	950.00	240.000	10.5000	0.78	0.400	0.120	82.7
10	16	10	0	1	950.00	240.000	10.5000	0.76	0.400	0.120	83.3
11	20	11	0	1	950.00	240.000	10.5000	0.77	0.400	0.120	82.9
12	3	12	1	1	600.00	330.000	9.5000	0.76	0.450	0.176	79.2
13	1	13	1	1	600.00	150.000	9.5000	1.17	0.357	0.111	76.1
14	12	14	-1	1	950.00	391.361	10.5000	0.70	0.450	0.267	74.0
15	17	15	0	1	950.00	240.000	10.5000	0.75	0.400	0.130	81.7
16	2	16	1	1	1300.00	150.000	9.5000	0.80	0.357	0.230	49.9
17	6	17	1	1	1300.00	150.000	11.5000	0.78	0.357	0.080	86.5
18	9	18	-1	1	361.37	240.000	10.5000	0.36	0.400	0.450	53.0
19	11	19	-1	1	950.00	88.639	10.5000	2.12	1.480	0.600	82.9
20	15	20	0	1	950.00	240.000	10.5000	0.76	0.400	0.120	83.1

Fig 1. *Experimental design and their corresponding results*

Response Surface Regression: Recovery(%) versus CN, PS, pH

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The analysis was done using coded units.

Estimated Regression Coefficients for Recovery(%)

Term          Coef  SE Coef        T      P
Constant   82.1595    2.560   32.099  0.000
CN          6.9202    1.698    4.075  0.002
PS         -3.5197    1.698   -2.073  0.065
pH          0.2183    1.698    0.129  0.900
CN*CN      -5.0801    1.653   -3.073  0.012
PS*PS      -0.8551    1.653   -0.517  0.616
pH*pH      -9.4995    1.653   -5.746  0.000
CN*PS       9.7125    2.219    4.377  0.001
CN*pH      12.6125    2.219    5.684  0.000
PS*pH     -12.3125    2.219   -5.549  0.000


S = 6.27578    PRESS = 3054.19
R-Sq = 93.45%  R-Sq(pred) = 49.19%  R-Sq(adj) = 87.55%
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Fig 2. *Analysis of variance (ANOVA) for model regression*

3.2. Effects of Vat leaching Parameters on Gold Recovery

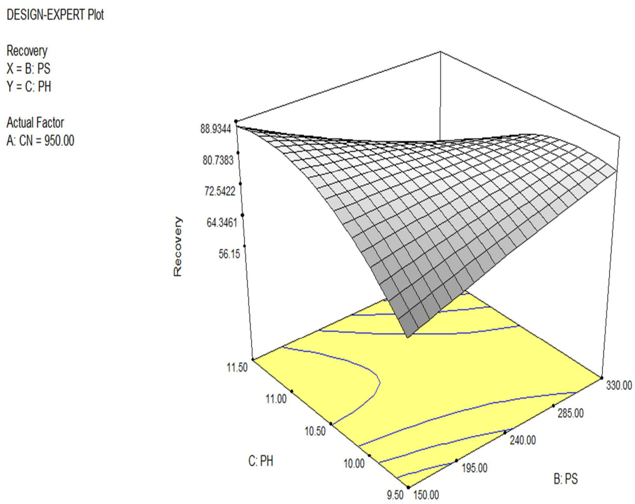

Fig 3. *Effect of slurry pH and particle size on gold recovery*

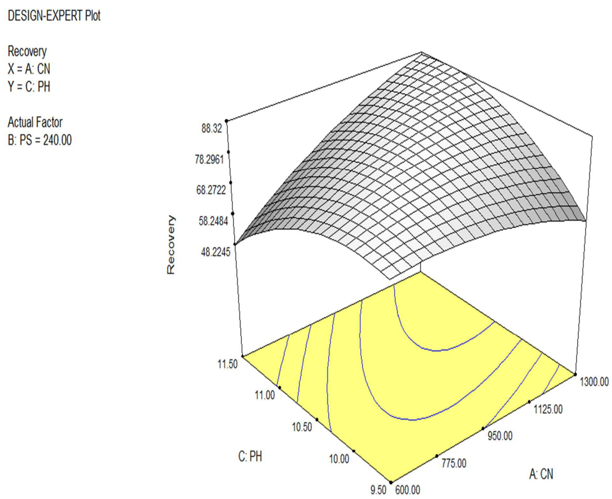

Fig 4. *Effect of slurry pH and cyanide concentration on gold recovery*

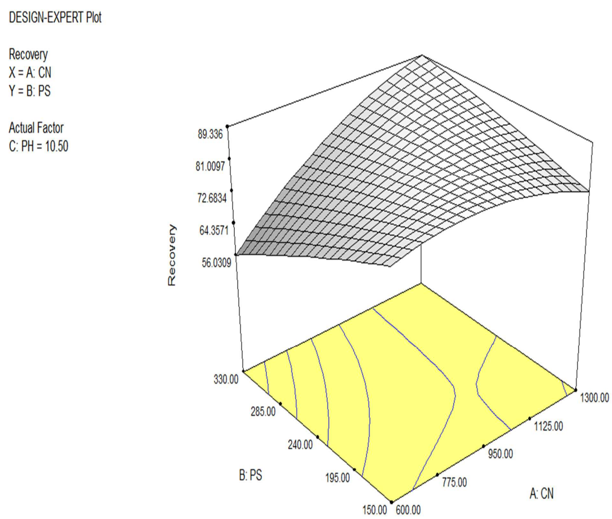

Fig 5. *Effect of slurry pH and cyanide concentration on gold recovery*

Fig 3, 4 and 5 show the response of the interactive parameters i.e slurry pH, particle size and cyanide concentration. The response (gold recovery) is direct proportional to the increase of slurry pH and cyanide concentration, but beyond the slurry pH of 10.5, gold leach recovery starts to trend down, this is probably because the adsorption of OH^{-} ion onto gold surface decreases the surface available for cyanide leaching. In other hand gold leach recovery shows to decrease as the particle size is above 240 µm probably because most of mineral of interest (gold particles) are not exposed to reagent and hence the available contact surface area of gold particles to reagents (sodium cyanide and dissolved oxygen) is reduced [8, 12]. The highest gold leach recovery was observed at slurry pH of 10.5, particle size 240 µm and 950 ppm of cyanide.

4. Conclusion

The RSM and CCD design were used to determine the optimal vat leaching operating parameters conditions. The study revealed that, with cyanide concentration of 950 ppm, particle size of 240 µm and slurry pH of 10.5, small scale mine operation at Nyarugusu, Geita Tanzania can improve their gold leach recovery to 83%. This is significant improvement compared with the current recovery of between 60-70%.

References

[1] J. Marsden and I. House, *The Chemistry of Gold Extraction*, West Sussex, England: Ellis Horwood, 1992.

[2] La Brooy, S.R., Linge, H.G. and Walker, G.S. (1994) Review of Gold Extraction from Ores. *Minerals Engineering*, 7, 1213-1241. http://dx.doi.org/10.1016/0892-6875(94)90114-7

[3] Rubisov, D.H., Papengelakis, V.G. and Kondos, P.D. (1996) Fundamental Kinetic Models for Gold Ore Cyanide Leaching. *Canadian Metallurgical Quarterly*, 35, 353-361. http://dx.doi.org/10.1179/cmq.1996.35.4.353

[4] Adams, M.D. (2005) Advances in Gold Ore Processing, Developments in Mineral Processing. Elsevier, Amsterdam

[5] Chryssoulis, S.L. and McMullen, J. (2005) Mineralogical Investigation of Gold Ores. In: Adams, M.D., Ed., *Advances in Gold Ore Processing*, Elsevier, The Netherlands, 21-71. http://dx.doi.org/10.1016/S0167-4528(05)15002-9

[6] Chen, T., Cabri, J. and Dutrizac, E. (2002) Characterizing Gold in Refractory Sulfide Gold Ores and Residues. *Journal* of Minerals, Metallurgy and Materials, 54, 20-22.

[7] P. Ling, V.G. Papangelakis and S.A. Argyropoulos, An Improved Rate Equation for Cyanidation of a Gold Ore. *Can. Metall. Q.*, 35(1996), No 3, pp. 225-234

[8] P.D. Kondos, G. Deschênes, and R.M. Morrison, Process Optimization Studies in Gold Cyanidation, *Hydrometallurgy*, 3 (1995), pp. 235-250.

[9] G. Deschênes and G. Wallingford, Effect of Oxygen and Lead Nitrate on the Cyanidation of a Sulphide Bearing Gold Ore. *Miner. Eng.*, 8(1995), pp. 923-931.

[10] G. Deschênes and P.J.H. Prud'homme, Cyanidation of Copper-Gold Ore. *Int. J. Miner. Process*, 50(1997), pp. 127-141.

[11] Ogundare, O.D., Adeoye, M.O., Adetunji, A.R. and Adewoye, O.O. (2014) Beneficiation and Characterization of Gold from Itagunmodi Gold Ore by Cyanidation. *Journal of Minerals and Materials Characterization and Engineering*, 2, 300-307. http://dx.doi.org/10.4236/jmmce.2014.24035

[12] S. Ellis, and G. Senanayake, The Effects of Dissolved Oxygen and Cyanide Dosage on Gold Extraction from a Pyrrhotite-Rich Ore. *Hydrometallurgy*, 72(2004), pp. 39-50.

[13] L.R.P. De Andrade Lima and D. Hodouin, A Lumped Kinetic Model for Gold Ore Cyanidation. *Hydrometallurgy*, 79(2005), pp. 121-137.

[14] X. Dai and M.I Jeffrey, The Effect of Sulfide Minerals on the Leaching of Gold in Aerated Cyanide Solutions. *Hydrometallurgy*, 8 (2006), pp. 118-125

[15] M. M. Aghamirian and W.T. Yen, Study of gold of gold anodic behavior in the presence of various ions and sulfide mineral in cyanide solution. *Miner. Eng.*, 18(2005), pg 89-102.