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Optimization of cyanidation parameters to increase the capacity of Aghdarre gold mill

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Abstract

This study investigates the optimization of gold dissolution from Aghdarre ore. Therefore, a laboratory investigation was initiated, to improve the leaching conditions with the objective of maximizing mill capacity with no reduction on gold recovery. It was observed that the time reduction from 25 to 15 hours did not change gold recovery. In other words, it indicated that a capacity of 140t/h can be sustained without any detrimental effect on gold recovery. The optimum parameters were 700g/t NaCN, 46% solid in pulp, pH=10, and d_{80}=45 microns using the Taguchi method. So, the gold recovery was obtained 90.71%. Also, it was concluded that the NaCN concentration was the most effective parameter and the solid percent plus retention time had the lowest effect on this process.

Keywords: *Optimization, Cyanidation, Gold, Taguchi, Aghdarre.*

1. Introduction

The optimum effect of several variables in gold cyanidation has been frequently addressed by researchers in their effort to improve gold processing. Their findings have been diverse depending on the operating conditions and the mineralogical composition of the gold ores. Although gold cyanidation plant practice in Aghdarre has improved significantly in recent years, process optimization is still under development.

Cyanide has been the universal reagent for gold leaching on counts of higher stability, lower cost and better understood chemistry. The cyanide salts such as sodium cyanide, potassium cyanide and calcium cyanide are the most effective agents in gold cyanidation plant. These salts are ionized in water to release free cyanide ions [1, 2]. Also, the sodium and potassium cyanide are more suitable than calcium cyanide in gold dissolution process. Gold oxidation in alkaline cyanide solution is the main requirements in this process. Although gold is neutral in oxidation process, but cyanide can oxidized gold and form a stable and solvable complex ion $Au(CN)_2^-$. This process takes place in to two stages as below [1, 3-6]:

$$2Au + 4CN^- + O_2 + 2H_2O \leftrightarrow 2Au(CN)_2^- + H_2O_2 + 2OH^- \quad (1)$$

$$2Au + 4CN^- + H_2O_2 \leftrightarrow 2Au(CN)_2^- + 2OH^- \quad (2)$$

So the Elsner Equation is achieved as below [1, 7]:

$$4Au + 8CN^- + O_2 + 2H_2O \leftrightarrow 4Au(CN)_2^- + 4OH^- \quad (3)$$

Some of the most effective parameters in cyanidation process are dissolved oxygen concentration, the free cyanide concentration, pH, particle size and operating conditions. The dissolved Oxygen concentration determines the cathode reduction of dissolved oxygen and may be supplied by air or pure oxygen. It depends on the temperature and pressure of operation conditions [1]. In other words, its solubility increases by decreasing temperature and increasing partial pressure of oxygen [3, 8]. The gold extraction rate increases by increasing the concentration of free cyanide but high cyanide concentration does not affect the gold dissolution rate. The excessive cyanide causes the complexes of cyanide with system impurities. So, if the sample contains sulfide compounds, then more cyanide may be needed [1, 3, 9, 10 and 11]. Also, it is expected that the gold dissolution rate decreases by increasing the pH because OH^- ions are adsorbed on gold surface and prevent cyanide to access the gold surface. Also, this may be due to the competition between sulfides species and gold to react with free cyanide [12].

The other effective parameter is particle size and the gold dissolution rate will increase by decreasing the particle size, because the contact area will be increased [3, 13]. It should be noted that more particle size reduction will increase the cyanide consumption [1]. Also, the temperature has a significant effect on gold dissolution. It decreases the viscosity of aqueous phase and increases the diffusivity but it decreases the Oxygen dissolution rate. This process is carried out in the ambient temperature because the higher solubility of impurities occurred at higher temperature [1]. The pressure has the same effect as temperature and the gold extraction can increase by Increasing the temperature and pressure together [3, 14].

The pulp density is the other effective parameter which causes to increase the retention time and decrease the reagents consumption with increasing it. Also, the dissolution rate of gold depends on the thickness of diffusion layer, so that particles diffusion shall be optimized by mixing because it may reduce the diffusion layer thickness [1, 14].

In this research work, a cyanidation study was conducted to investigate the effective parameters in gold cyanidition process and improve the leaching conditions. In other words, the aim of this work is to determine the necessary retention time of the leach circuit and the optimal gold extraction and cyanide consumption with the objective of maximizing mill capacity with no reduction on gold recovery.

2. Materials and methods

2.1. Statistical approach

As mentioned above, the effective parameters of gold cyanide leaching are NaCN concentration, pH, solid percent, d_{80} and retention time. The impact of these parameters on gold recovery were studied by Taguchi statistical approach using Qualitek-4 software [15- 18].

In order to determine the maximum recovery of gold leaching, these parameters were selected in two and three levels. As the sodium cyanide had negligible effect on the pH, so these two parameters were considered independently. The dissolved oxygen concentration in the pulp was 6mg/l in industrial scale so there were some holes on the bottle cap to aerate the pulp in lab scale, but it was impossible to measure the amount of dissolved oxygen in the lab scale, which was due to the mixing condition and low volume of experiments in this scale.

It should be noted that the range of parameter values were selected in such a way that it could be implemented as the plant operating conditions. Due to the operational restriction, the solid percent was considered less than 42%, because the clay compounds in the ore congest the inter tank screens at the solid percent more than 42 and then the leaching tanks would be overloaded. Since the vortex and spigots of the hydro-cyclones can also change, the feed particle size could change.

2.2. Experimental methods

The Aghdarre gold mill samples are used for all experiments. The Aghdarre gold mill is in the 32 km of north of Takab city in west Azarbayjan province of Iran. The samples, which were taken from SAG mill feed, were crushed by jaw crusher and were divided into 1kg portion in several stages and prepared for leaching experiments. All experiments were carried out in Pouyazarkan mineral processing lab. The pulp was prepared in the tumble bottle and the pH was adjusted, then the sodium cyanide (prepared by MERK Company) was added to the pulp and the pulp was mixed as shown in Figure 1. There were some holes on the bottle cap to aerate the pulp. The pulp volume in all experiments were considered as 1 liter and the pH was adjusted by $Ca(OH)_2$ and H_2SO_4. After each experiment, the sample was filtered and the liquid phase was analyzed for the gold content and free cyanide. The gold was analyzed by PerkinElmer 200 atomic absorption device after extraction of gold by DIBK solvent and the mercury was analyzed by UV device. The free cyanide concentration was then determined by titration with $AgNO_3$ in the presence of potassium iodide (KI). In addition, the HANNA 100 Oxygen meter was used to analyze the amount of aqueous oxygen.

Figure 1. Cyanide leaching using bottle roll.

2.3. Mineralogical studies

Mineralogical studies indicated that the degree of freedom was 20 microns as size, and regarding to mineralogical tests, the hosted minerals were oxide minerals, Iron hydroxide (Goethite), manganese, silicate and in some cases arsenate and sulfides.

Typically, cyanide destruction was employed to prevent the discharge of some metal cyanide (like copper) into tailings storage facilities. This imposed a significant financial cost on producers from the additional cyanide used to solubilize the metal and the cost of cyanide destruction reagents [19]. In this sample, the microscopic studies showed that the amounts of sulfide minerals (cyanide consumer) which competed with the gold particles in cyanidation process were neglected, so the pre-leach process was not used in these tests.

The atomic absorption and XRF analysis are shown in Tables 1 and 2 respectively and the XRD is shown in Figure 2. Results presented that the major minerals are Quartz, Calcite, Barite, Jarosite and Kaolinite.

Table 1. Atomic absorption analysis.

Element	Au(ppm)	Ag(ppm)	Hg(ppm)
Grade	2.7	6.5	170

Table 2. XRF analysis.

Chemical compounds and elements	%	Chemical compounds and elements	%
Fe_2O_3	10.26	ZnO	0.54
MnO	1.61	MgO	>0.01
TiO_2	0.41	Cl	0.104
CaO	52.11	PbO	0.745
K_2O	1.81	BaO	2.43
SO_3	1.80	Sb_2O_3	0.3
P_2O_5	>0.01	SrO	0.099
SiO_2	49.59	As_2O_3	2.53
Al_2O_3	11.38	L.O.I	4.852

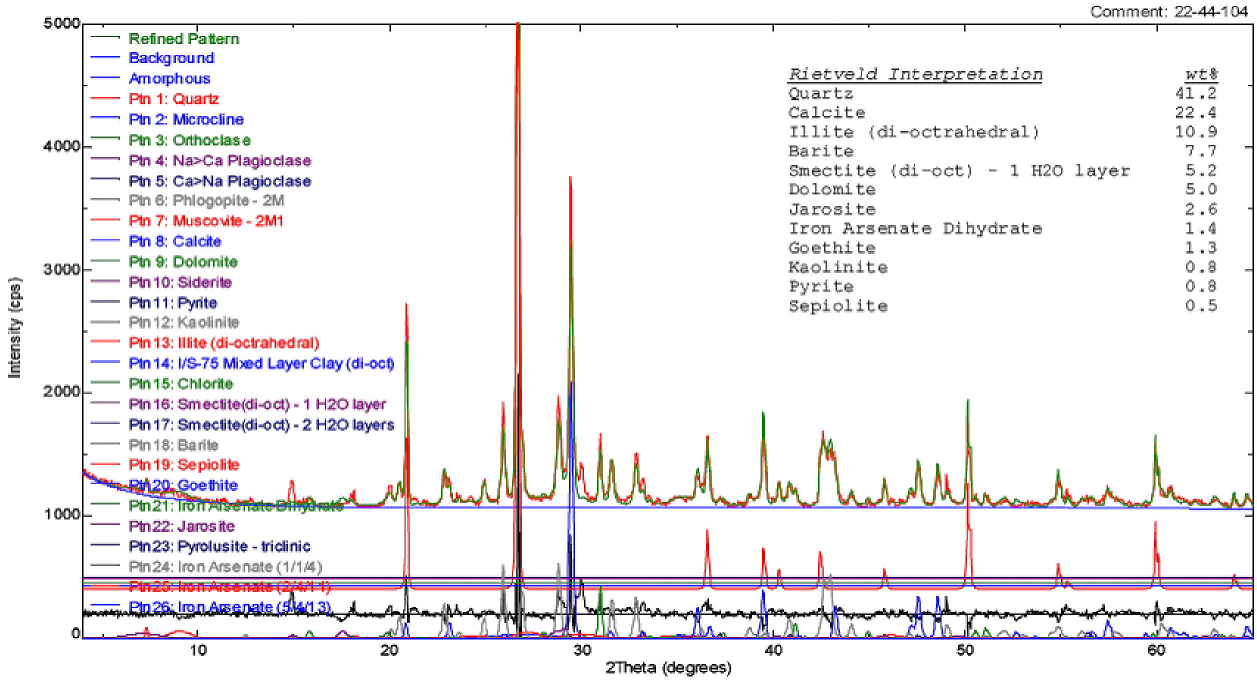

Figure 2. XRD analysis.

3. Results and discussion

The main parameters and their values in gold leaching of the plant are presented in Table 3. The experiments were conducted in these conditions. As the amount of dissolved oxygen and the mixing rate could not be changed in the plant (due to the plant restrictions), these parameters were fixed in experiments.

Table 3. The values of leaching parameters on Pooyazarkan mineral processing mill.

Parameter	Value
Sodium cyanide	1450 ppm (Free cyanide concentration is 500 ppm)
Dissolved Oxygen	4-6 mg/l
pH	10-10.5
Solid Percent	38
d80	75 micron
Residence Time	28 hours (based on 75tph feed capacity)
Gold Recovery	89%

In order to determine the maximum recovery of gold leaching by Taguchi method, the sodium cyanide, pH, solid percent, d_{80} and residence time parameters were chosen at two levels. The dissolved oxygen concentration in the pulp was obtained 6mg/l, which is due to the mixing condition, stirring speed, low volume of tests and dissolved oxygen during mixing at the lab scale, whereas in the industrial scale due to the high volume of mixing tanks and low speed stirring, adding dissolved oxygen to the tank is necessary.

It is noted that the range of parameter values was selected in such a way that it could be used in the plant operating conditions. Due to the operational restriction, the solid percent was considered less than 42%, because the clay compounds in the ore congest the inter tank screens at the solid percent more than 42 and then the leaching tanks would be overloaded.

According to a number of parameters (5 parameters and 4 interactions), the L16 array was selected for the optimization of cyanide leaching process and the experiments were carried out. The results of these experiments and their analysis of variance (ANOVA) are presented in Table 4, 5 and 6 respectively.

Table 4. The L16 array to determine the gold recovery.

Run	CN (g/ton)	pH	CN×pH	S (%)	CN×S	CN×d_{80}	d_{80} (micron)	CN×T	T (hours)	Gold Recovery%
1	700	10	1	34	1	1	53	1	20	86.24
2	700	10	1	34	1	1	53	2	30	87.39
3	700	10	1	42	2	2	75	1	20	84.48
4	700	10	1	42	2	2	75	2	30	86.51
5	700	11	2	34	1	2	75	2	30	83.39
6	700	11	2	34	1	2	75	1	20	82.81
7	700	11	2	42	2	1	53	2	30	86.11
8	700	11	2	42	2	1	53	1	30	86.5
9	1500	10	2	34	2	1	75	1	20	84.8
10	1500	10	2	34	2	1	75	2	30	84.95
11	1500	10	2	42	1	2	53	1	20	87.6
12	1500	10	2	42	1	2	53	2	30	87.1
13	1500	11	1	34	2	2	53	2	30	86.7
14	1500	11	1	34	2	2	53	1	20	85.9
15	1500	11	1	42	1	1	75	2	30	84.26
16	1500	11	1	42	1	1	75	1	20	84.9

Table 5. ANOVA results for gold recovery after pooling (confidence level 90%).

Parameters	Freedom degree (f)	Sum of the squares (S)	Variance (V=S/f)	Sum of the squares net (S')	Variance ratio F=(V/Ve)	Effect percentage (S'/ST)×100
Sodium cyanide	1	0.496	0.496	0.08	1.194	0.266
pH	1	4.518	4.518	4.102	10.879	13.526
CN×pH	(1)	(0.611)	POOLED	POOLED	POOLED	POOLED
Solid percent (S)	1	1.755	1.755	1.34	4.226	4.418
CN×S	(1)	(0.342)	POOLED	POOLED	POOLED	POOLED
d_{80}	1	19.022	19.022	18.607	45.804	61.345
CN× d_{80}	1	0.04	POOLED	POOLED	POOLED	POOLED
Resident time (T)	1	0.378	0.378	0	0.931	0
T×d_{80}	(1)	(0.252)	POOLED	POOLED	POOLED	POOLED
Error (e)	11	4.152	0.415			20.445
Sum	15	30.332				100

Table 6. Optimum levels of effective parameters in gold recovery.

Parameter	Level NO.	Value
CN	2	1500 g/ton
pH	1	10
S	2	42%
d_{80}	1	53 micron
T	2	30 hours

Figure 3 was plotted based on the recovery of L16 array for each parameter. It can be seen that the cyanide dosage and retention time had negligible effect on recovery, but according to previous researches, increasing the cyanide dosage and retention time lead to an increase in gold recovery; hence, it means that the selected low level of these parameters was near the optimum and increasing the value of these parameters led to dissolving the impurities. So these two parameters were considered in next step experimental design.

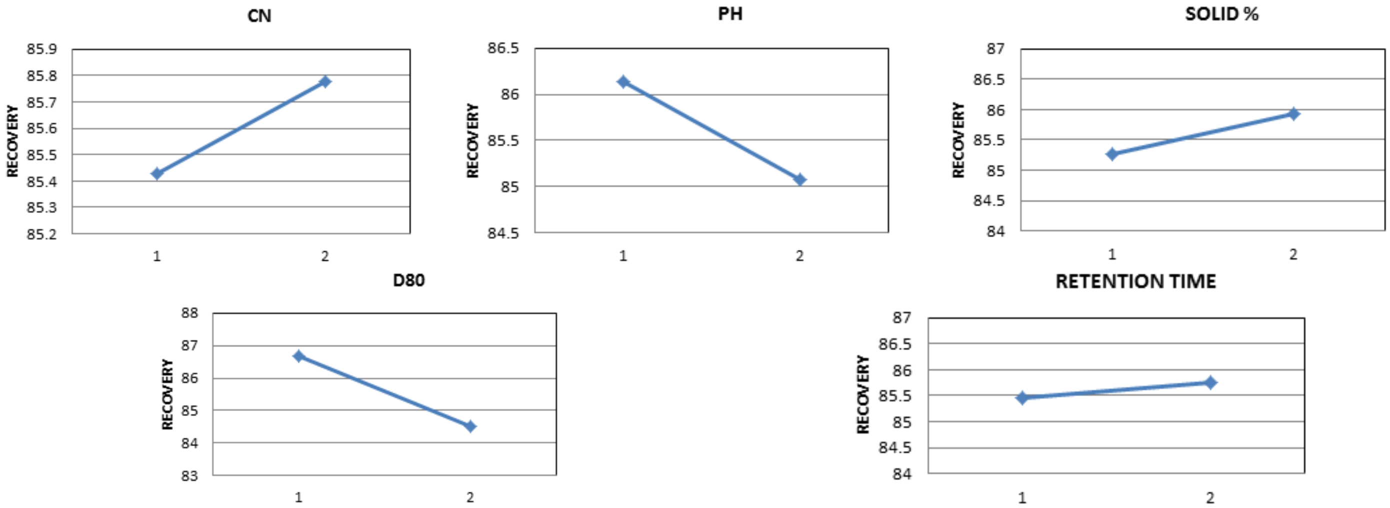

Figure 3. Gold recovery variations at two selected levels.

As it is observed in Table 5, the effective parameter of this process was particle size and the interaction between parameters was negligible. So, the optimum condition is shown in Table 6 (Run 12).

Because of the negligible and effective parameters, the following parameters were carried out in three levels: the NaCN concentration, pH, solid percent, d_{80} and residence time.

The results are shown in Figure 4 based on the L18 array. It is observed that the sodium cyanide concentration had the most significant effect and the solid percent and retention time had the lowest effect on gold recovery.

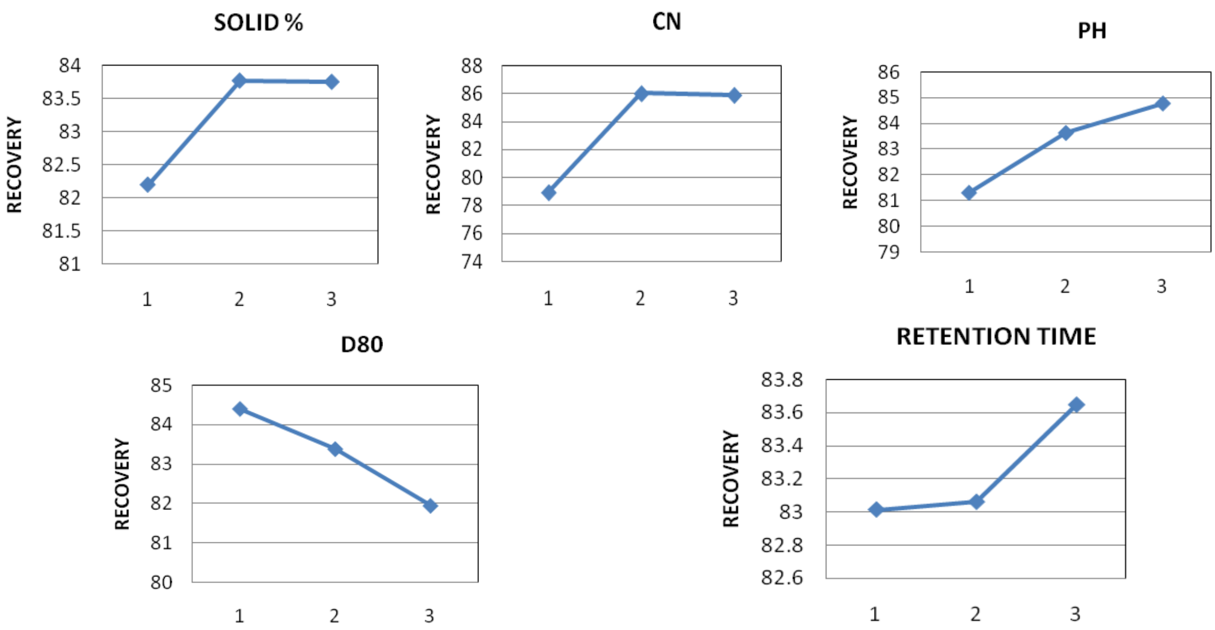

Figure 4. Gold recovery variations at three selected levels.

Table 3 shows that the plant retention time was 28 hours for the capacity of 75t/h. Moreover, the experimental results in Table 7 show that the retention times within 15 up to 25 has no effect on gold recovery. In other words, changes in retention time from 15 to 25 did not influence gold solubiliation to any greater extent. It is concluded that the gold solubility was high and increasing the capacity up to about 140 tph (reduce the retention time to 15 hours) did not reduce the recovery.

The opportunity of other impurities to consume cyanide and formed complex increased by increasing the retention time and therefore the plant capacity would be decreased. For example, the adsorption of impurities complex in competition with gold complex on activated carbon caused to occupy some part of the activated carbon surface, so the capacity would be decreased. In addition, by increasing the amount of impurities adsorption on carbon surface the reagent consumption would increase.

According to gold recoveries (Table 7), the analysis of variance (ANOVA) and the optimum levels of parameters are presented in Tables 8 and 9 respectively. Also, the predicted recovery values in optimum conditions after pooling at the confidence level 90%, and the final result are shown in Table 10.

Table 7. The L18 array plan to determine optimized values and gold recovery for each experiments.

Run	CN (g/ton)	pH	S (%)	d_{80} (micron)	T (hours)	Gold Recovery (%)
1	500	9.5	34	45	15	76.2
2	500	10	38	53	20	77.1
3	500	10.5	42	63	25	75.2
4	700	9.5	34	53	15	86.5
5	700	10	38	63	25	86.8
6	700	10.5	42	45	15	84.3
7	900	9.5	38	45	25	88.6
8	900	10	42	53	15	86.9
9	900	10.5	34	63	20	80.1
10	500	9.5	42	63	20	78.2
11	500	10	34	45	25	80.8
12	500	10.5	38	53	15	79.3
13	700	9.5	38	63	15	84.9
14	700	10	42	45	20	90.53
15	700	10.5	34	53	25	83.09
16	900	9.5	42	53	25	87.39
17	900	10	34	63	15	86.48
18	900	10.5	38	45	20	85.93

Table 8. ANOVA results for gold recovery (confidence level 90%).

Parameters	Freedom degree (f)	Sum of the squares (S)	Variance (V=S/f)	Sum of the squares Net (S')	Variance ratio F=(V/Ve)	Effect percentage (S'/ST)×100
NaCN	2	266.379	133.189	258.285	32.913	70.556
pH	(2)	37.047	18.523	28.953	4.577	7.909
Solid percent	2	(9.815)	POOLED	CL = 98.59%	POOLED	POOLED
d80	2	18.128	9.064	10.035	2.239	2.741
Resident Time	2	(1.503)	POOLED	POOLED	POOLED	POOLED
Error (e)	11	44.513	4.046			18.794
Sum	17	366.069				100

Table 9. Optimum levels of effective parameters in gold recovery.

parameter	Level NO.	Value
CN	2	700 g/ton
pH	2	10
d_{80}	1	45 microns

Table 10. Recovery predicted and obtained in optimum conditions.

Metal	Predicted recovery (%)	Experimental recovery at optimum conditions (%)
Gold	88.69 ± 2.099	90.71

4. Conclusions

The results of leaching experiments are presented below:

- The microscopic studies of Aghdarre ore sample showed that the amounts of sulfide minerals (cyanide consumer), which were computed with the gold particles in cyanidation process were neglected so the pre-leach process was not used in these experiments.
- The optimum conditions of cyanidation process was CN = 700 g/t, pH = 10, d_{80} = 45 micron and the gold recovery in this condition was obtained 90.71%.
- The results of experimental design showed that the solid percent had little effect on gold recovery; therefore; there was the possibility of clogging the screens due to the clay compounds in the ore. Therefore it is recommended that the solid percent is considered 38-40.
- In addition, the retention times within 15 up to 25 had no effect on gold recovery. It means that solubility of gold ore was high and increasing the capacity up to about 140 tph (reduce the retention time to 15 hours) did not reduce the recovery. Also, the opportunity of other impurities to consume cyanide and formed complex was increased by increasing the retention time and the plant capacity would be decreased.
- For samples with sulfide compounds, it was necessary to use more cyanide, but there was a little amount of sulfide minerals in the Aghdarre gold mine, so excessive cyanide addition was not necessary. Therefore, by imposing new conditions, more than 50% NaCN consumption was reduced.
- Increasing the pH (10 to 11) would decrease the gold recovery, because the OH^- ions were adsorbed on gold surface and prevent cyanide solution from accessing the gold surface.

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بهینه‌سازی پارامترهای سیانوراسیون در افزایش ظرفیت کارخانه طلای آق دره

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چکیده:

در این مقاله بررسی در مورد بهینه‌سازی حلالیت طلای موجود در ماده معدنی آق دره انجام‌شده است؛ بنابراین کار با بهبود شرایط انحلال، باهدف حداکثر کردن ظرفیت کارخانه، بدون کاهش بازیابی طلا آغاز شد. در این مطالعه مشاهده شد که کاهش زمان از ۲۵ به ۱۵ ساعت، موجب تغییر بازیابی طلا نشد. به‌عبارت‌دیگر، دلالت بر آن داشت که ظرفیت ۱۴۰ تن بر ساعت می‌تواند بدون هیچ تأثیر منفی بر بازیابی طلا ثابت بماند. مقادیر بهینه پارامترها که به روش تاگوچی به دست آمدند، عبارت‌اند از: ۷۰۰ گرم بر تن NaCN، درصد جامد پالپ ۴۶، pH=۱۰ و d_{80}=۴۵ میکرون. با توجه به این شرایط، بازیابی طلا برابر ۹۰/۷۱٪ به دست آمد. همچنین نتیجه‌گیری شد که غلظت NaCN بیشترین تأثیر و درصد جامد به‌علاوه زمان‌ماند کمترین تأثیر را در فرآیند داشتند.

کلمات کلیدی: بهینه‌سازی، سیانوراسیون، طلا، تاگوچی، آق دره.