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Research Paper

An Investigation of Ammonia Effect on Dissolution and Recovery of Gold in Cyanidation Process of Copper-Gold Ore

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Abstract: The presence of copper oxide next to gold increases the consumption of cyanide in the cyanidation process, reduces the absorption of gold on carbon, and causes many problems in the downstream processes of elution, electrowinning, and smelting. In the current research, increasing the recovery of gold dissolution and its selective adsorption on activated carbon using ammonia additive and the effect of different factors such as the type of ammonia additive, changing the system of contact of gold with carbon from CIL to CIC, and adding hydrogen peroxide and cyanide to the filtered solution were studied. The findings showed that adding ammonium chloride or liquid ammonia to the cyanidation solution, in the sample with high copper grade (1% copper), and in the sample with medium copper grade (0.5% copper), increased the dissolution recovery by 60% and 30%, respectively. Also, the recovery of gold adsorption on activated carbon in sample with a grade of 0.5% copper increased from about 25% during the normal CIL process to about 100% during the ammonia cyanidation process in the form of CIC. Results showed that liquid ammonia provides up to 10% higher dissolution recovery and up to 3% higher absorption recovery compared to ammonium chloride, while reduces the consumption of cyanide by half and the amount of copper absorption on carbon by a third.

Keywords: Cyanidation, Ammonia, Gold-copper ore, Absorption, Activated carbon.

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INTRODUCTION

In the last century, cyanidation has been the dominant method in gold processing plants all over the world, although it has been limited in many ores, especially copper-containing ores [1]. During the leaching process, most copper minerals and especially copper oxide minerals are soluble to varying degrees in cyanide solution and form copper complexes ($Cu(CN)_2^-$, $Cu(CN)_3^{2-}$ and $Cu(CN)_4^{3-}$) which their stability depend on the amount of free cyanide and undecomposed hydrocyanic acid. These copper-cyanide complexes cause various challenges, including in leaching, absorption by activated carbon, elution and electrowinning processes. In response to the challenges of soluble copper in gold ores, various methods have been evaluated by researchers. These methods include the use of flotation to reduce the copper in leaching feed [2], the use of cyanide alternatives such as thiourea [3,4] and thiosulfate [5], the use of additives such as glycine [6,7] and ammonia [8,9], the use of cyanide and copper recovery methods such as SART[1] [10,11], copper precipitation [12,13], and separation and recovery of dissolved copper by carbon (Serisini method) [14]. Among the additives, the use of ammonia has been tested on an industrial scale [15].

The effect of adding ammonia on the leaching kinetics of gold with cyanide has been investigated in several studies. It has been shown that adding ammonia reduces the rate of gold leaching when the solution does not contain copper. When copper is present in the solution, the rate of leaching without ammonia decreases due to the formation of copper cyanide complexes, and under zero free cyanide conditions, gold is practically dissolved by breaking the $Cu(CN)_3^{2-}$ complex. In this case, it has been found that the addition of ammonia has a little effect on the leaching of gold by $Cu(CN)_3^{2-}$, but when the main species is $Cu(CN)_2^-$, the kinetics of gold leaching in the presence of ammonia increases. Under these conditions, leaching is very slow in the absence of ammonia. The effect of addition of Cu(II) has also been studied and it has been found that in the absence of free cyanide, the presence of Cu(II) increases the leaching rate, provided that there is enough ammonia to stabilize it against reaction with cyanide-copper(I) complexes [16,17]. In general, adding ammonia to the cyanide solution can lead to decrease in cyanide consumption and increase in the selectivity of the gold leaching process over copper. But there will still be important challenges in the continuation of the process and in the absorption stage.

Various methods have been proposed to recover gold from copper-containing solutions, including gold cementation on zinc or copper metal, adsorption on activated carbon, or adsorption on ion exchange resins. In all cases, it is necessary to separate the clear solution from the leaching tailings, because the deposited copper in the tailings is slowly transferred to the carbon or resin [17]. The selective adsorption of gold on activated carbon in the gold-cyanide-ammonia-copper system is also possible only by using the CIC[2] method, because copper is present in the leaching tailings in the form of CuCN or $Cu(OH)_2$; and it is necessary to filter the pulp and recover the gold from the clarified filtrate solution using activated carbon. Also, the control of copper adsorption on activated carbon requires the addition of NaCN to minimize copper adsorption on carbon [17,18]. Although this operation is mentioned in very few literatures, no quantitative information is available in this field. Considering the importance of gold recovery after its dissolution, in this research, an attempt has been made to increase the amount of gold dissolution in different amounts of copper oxide in the feed by using ammonia additive in the form of liquid ammonia or ammonium chloride, and at the same time, by changing the interaction of gold with carbon from the CIL[3] to CIC system. The increase in gold absorption recovery is also investigated in this research.

METHODS

All experiments were performed using ore samples with an average gold grade of 2 ppm and an average copper grade of 1% and 0.5%. At first, in order to obtain the optimal conditions for cyanidation, cyanide-ammonia leaching experiments and absorption by activated carbon were performed in different concentrations of cyanide and ammonia, with a solid percentage of 33%, ambient temperature, pH=10.5-11, and a time of 24 hours. The way of conducting the tests using a rolling bottle was that after crushing up to 80% passing through a 75 micron sieve and preparing the sample, for each test, the amount of 812 grams of soil was measured with a digital scale and poured into the bottle along with water, so that the target percentage of solids was reached; Then, the desired amount of dissolving agent was added along with ammonia (in the form of ammonium chloride or liquid ammonia) and 3 cc of hydrogen peroxide (based on the previous experience of factory bottle roll tests) was added to provide the oxygen needed to carry out the leaching process. To adjust the pH, powdered lime was used. Cyanide-Ammonia leaching tests were performed in both CIL and CIC forms on the feed sample. CIL refers to a method in which carbon is added to the pulp at the beginning of the experiment and is separated from it at the end of the experiment; While in the CIC method, first the gold dissolution is done using cyanide and other additives, then the desired pulp is filtered and carbon is added to its solution containing gold, finally absorption is done. On an industrial scale, this operation is carried out in carbon absorption columns and therefore is called Carbon in Column (CIC); But in the experiments of this research, the absorption operation was not performed in the column, and beaker were given 100 cc of the pregnant solution filtered from teaching test, then carbon has been added and mixing by a magnetic stirrer has been done. After each experiment, the desired pulp was filtered and a 10 ml sample of the solution was taken for titration and determination of the free cyanide content of the solution. The final solid tailings were dried with the help of an oven at 100 degrees Celsius, and after drying, were re-shredded by a pneumatic disc grinder; After that, samples were taken from it for measuring gold and copper. At the end, solution samples, feed and solid tailings samples, and activated carbon samples were assayed to determine gold and copper grades.

In this article, to investigate various factors of dissolution and absorption of gold on activated carbon in cyanide-ammonia system, a total of 10 experiments were conducted which includes the following. In order to compare the two methods of CIL and CIC in ammonia cyanidation, four experiments were conducted with the same conditions to investigate the effect of adding ammonium chloride on the absorption of gold and copper on activated carbon. The first experiment was CIL without ammonia (optimal conditions obtained from previous tests); The second test was by the same conditions as the first test, but with ammonium chloride; and the third and fourth tests had similar conditions in the leaching phase, but in the absorption phase they were different. In the fourth experiment, 1.5 g/l of cyanide was added in the absorption stage. In order to compare the effect of adding ammonium chloride and liquid ammonia on the absorption of gold and copper on activated carbon, three tests were performed with the same conditions. All the three tests were performed under completely similar conditions, even in the amount of cyanide and ammonia. However, in test number 5, ammonium chloride was used and in the other two tests (tests number 6 and 7) liquid ammonia was used. Also, in order to increase the absorption, three ammonia cyanidation tests were performed using the CIC method using different amounts of carbon. In these tests, the optimal conditions found in the previous tests were used for the leaching stage (dissolution conditions of test no. 7) and a solution was prepared to perform absorption tests with different amounts of carbon to increase the amount of gold absorption (tests No. 8, 9, and 10 had 7, 5, and 15 g/l of active carbon, respectively).

FINDINGS AND ARGUMENT

According to the results of tests 1 to 4 (Table 1), in the comparison of CIC and CIL methods and the addition of cyanide in the absorption stage, although the addition of ammonium chloride in the CIL system significantly increased gold dissolution (from about 30% in test 1 to about 80% in test 2) and the amount of gold adsorbed on carbon almost doubled (from about 20 ppm to over 40 ppm), the overall adsorption recovery is still low. Especially in test 2 and 3, where the leaching conditions are the same and one is done as CIL and the other as CIC respectively, no special effect is observed. However, in the comparison of tests 3 and 4, in the absorption stage of test 4, when the amount of 1.5 g/l of cyanide was added to the filtered solution, the recovery of gold absorption from the solution increased by about 20% and the amount of copper absorption decreased slightly. An argument to justify these results is that due to the ratio of copper to gold (5000 ,10000 to 2), the ammonia used in the leaching process could not form complex with all the coppers and some of the coppers were in the form of copper-cyanide complexes. The addition of cyanide in the absorption stage caused the formed copper complexes, which are mostly in the form of $Cu(CN)_2^-$ and susceptible to adsorption on activated carbon, to become $Cu(CN)_3^{2-}$ and $Cu(CN)_4^{3-}$, which are less absorbed on activated carbon. As a result, the amount of copper adsorbed on activated carbon has decreased (from above 15000 ppm to below 1100 ppm); On the other hand, the interference effect of copper on the absorption of gold on carbon has decreased and the amount of gold adsorbed on activated carbon has increased. Why the overall absorption rate is still low can be due to the low amount of carbon compared to the amount of copper and gold in the solution. For this reason, tests have been conducted in this direction, the results of which are presented in the next paragraphs.

In comparing the effect of ammonium chloride and liquid ammonia on the dissolution and absorption of gold and copper on activated carbon, according to the results of tests 5 to 7 (Table 1), recovery of dissolution in the tests performed with liquid ammonia (by reducing the consumption of cyanide to half) increased up to 10% higher than the test done with ammonium chloride. On the other hand, by comparing the absorption recovery of gold from the solution in the tests that used ammonium chloride and liquid ammonia, it can be seen that the amount of absorption recovery in the tests that used liquid ammonia (test 6 and 7) has increased relatively. It can also be seen in the comparison of tests 6 and 7 that the gradual addition of cyanide and ammonia to the leaching solution does not have much effect on increasing the recovery of gold dissolution. The significant and important point in these tests is the amount of copper absorption on activated carbon. As can be seen in Table 1, the amount of copper absorption in the tests that used liquid ammonia is between 315 and 334 ppm, while in the tests that used ammonium chloride, in the best case, the lowest amount of copper absorption on carbon is 1091 ppm and this shows that when liquid ammonia is used instead of ammonium chloride, the amount of copper adsorption on activated carbon is greatly reduced. In test number 4, which used 1.78 g/l of activated carbon, the amount of gold absorption reached a maximum of 40%. However, when the amount of active carbon of 5 g/l was used in the absorption stage (test 9), the recovery of gold absorption was about 93%, and in cases where the amount of carbon was more than 5 g/l (test 8 and 10), gold absorption has increased to 98%. The important point is that in CIL conditions and in the presence of high soluble copper, adding more carbon has no advantage, and the more carbon is added to the solution, the more copper is absorbed from the solution, as the amount of copper is high compared to gold (about 1000 ppm of copper against 1 ppm of gold). However, in CIC condition and when adding cyanide to the separated solution can prevent the absorption of copper on carbon, the addition of carbon can be easily done. It should be noted that the numbers of 5 or 10 or 15 g/l are not high numbers compared to the concentration of industrial carbon used in normal gold factories.

Table 1. Results of the experiments

Test number	Feed grade (ppm)		Tailings grade (ppm)		Grade of the solution before absorption (ppm)		Grade of the solution after absorption (ppm)		Activated carbon grade (ppm)		Recovery of dissolution (%)		Absorption recovery from solution (%)	
	Gold	Copper	Gold	Copper	Gold	Copper	Gold	Copper	Gold	Copper	Gold	Copper	Gold	Copper
1	2.51	11130	1.72	10487	CIL		140	611	19.6	15170	31.3	5.8	25.6	71.58
2	2.37	11272	0.48	10417	CIL		330	737	44.7	16199	79.6	7.6	39.1	79.32
3	2.53	11450	0.57	10287	538	1828	397	419	42.9	15706	77.4	10.2	26.2	77.1
4	2.24	11321	0.42	10796	558	936	311	462	48.7	1091	81.4	4.6	44.3	50.6
5	2.34	11294	0.48	10459	532	934	268	449	104.7	1138	79.5	7.4	49.6	51.9
6	1.98	10248	0.26	9701	498	592	183	567	137.7	334	86.8	5.3	63.3	4.2
7	1.86	10238	0.16	9770	422	559	268	541	87.7	315	91.5	4.6	36.5	3.2
8	2.11	4812	0.5925	4324	428	340	11	333	76.33	793	71.9	10.1	97.3	2.1
9	2.16	4517	0.698	4458	441	358	32	306	63.33	2618	67.6	1.3	92.7	14.5
10	2.17	4873	0.6305	3123	396	1736	8	557	96.33	2625	70.9	35.9	97	67.9

CONCLUSIONS

- Results show that by adding ammonium chloride or liquid ammonia to the cyanidation solution, the recovery of gold dissolution has increased from 31% to 91.5% in the sample with high copper grade (1% copper).
- Due to the presence of copper in the leaching tailings in the form of CuCN or $Cu(OH)_2$, for more gold absorption and also less copper absorption from the solution on activated carbon, it is necessary to replace the CIL system with the CIC system in the cyanidation process. In this case, according to the results obtained in the best case, if the gold dissolution recovery is 92% and its absorption recovery is about 100%, due to the loss of approximately 20% of the gold containing solution in the CIC method along with the moisture

of the waste filtered cake, the final recovery will be about 73%. Of course, if the filter press is able to wash the cake, this loss of gold along with the waste cake will be reduced and the total recovery will be higher.

• According to the concentration ratio of copper to gold in the solution (5000 to 10000 to 2), the ammonia used in the leaching process could not form a complex with all the coppers and some of the coppers were in the form of copper-cyanide complexes. Therefore, the free cyanide added in the absorption stage causes the formed copper complexes, which are mostly in the form of $Cu(CN)_2^-$and susceptible to adsorption on activated carbon, to become $Cu(CN)_3^{2-}$ and $Cu(CN)_4^{3-}$, which are less absorbed on activated carbon.

• Results show that when liquid ammonia is used instead of ammonium chloride, the amount of gold dissolution is 5-10% more and the amount of copper adsorption on activated carbon is reduced. At the same time, cyanide consumption is reduced by half. This phenomenon has not been reported before.

• By changing the absorption system from CIL to CIC, adding cyanide to the leached solution, and reducing the amount of copper absorption on carbon, it is possible to increase the amount of carbon to the usual level of copper-free plants and increase the absorption recovery to about 100%.

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[1] Sulfidization, Acidification, Recycling, and Thickening (SART)

[2] Carbon in Column

[3] Carbon in Leach