

Gold Leaching Problems and Solutions at the Altan Tsagaan Ovoo Mine

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Abstract

The Altan Tsagaan Ovoo gold mine is mining a gold-polymetallic deposit that is comprised of oxide, sulfide, and transitional ore that originated from epithermal breccia pipes. The mine is located in the continental rift zone of the Mesozoic era in eastern Mongolia.

Mining and stacking of the heap leach pad started in 2019, and leaching operations were initiated in 2020. During warm weather the irrigation system consists of a sprinkler, and during cold weather a dripper system is used. The gold and silver is recovered using a carbon-in-column plant. The process is continuously enhanced through research and laboratory experiments.

Due to restrictions related to the COVID-19 pandemic, the processing plant was faced with a long-term shortage of the main key chemicals, especially cyanide, during 2020. Notwithstanding the shortages of key chemicals during that time, the solution continued to be circulated through the heap and plant. It took approximately six months for the cyanide content to be fully used up, allowing for the recovery of some silver and gold each month.

Due to the lower cyanide content, copper adsorption dramatically increased, leading to a significant deterioration in gold adsorption. The carbon and the cycle solution became highly contaminated, to the point where the carbon contained 10% copper, and the solution contained approximately 270 ppm of copper. In order to stop copper adsorption from obstructing gold adsorption, research was conducted into the following method: using carbon as a filtering agent and removing metal copper by desorption after adsorption of gold, silver, and copper in activated carbon. The gold sludge containing silver and copper mix was dissolved in nitric acid two to three times in order to recover copper; a caustic soda was used; and sugar to recover silver sugar was used in in the nitric acid. Once digestion was complete, a fine gold powder remained.

Following extensive research, it was found that when cyanide is insufficient, copper mono-cyanide and di-cyanide are formed, which is actively adsorbed in the carbon. This active copper compound was

observed to create stronger bonds with activated carbon than gold, which has the potential to even displace gold adsorbed in the carbon.

Based on this research, an experiment was conducted that changed the cyanide content of the solution and measured the copper adsorption amount in solutions after different time durations. This resulted in increased cyanide content and decreased copper adsorption, and required up to three days to complete the reaction of cyanide and copper.

This paper will focus on the process of stopping copper adsorption and copper removal from cycle solutions, and gold refining from high copper-content ores.

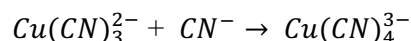
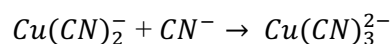
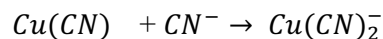
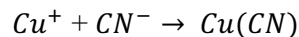
Introduction

This table shows an analysis of the oxide gold ore.

Table 1: An analysis of the oxide gold ore

Hole ID	Sample ID	Au, ppm	Ag, ppm	Cu, ppm	Pb, ppm	Zn, ppm
ATO-01	Z10002	2.32	7.70	215.00	2,320.00	261.00
ATO-01	Z10003	1.04	7.70	342.00	2,110.00	280.00
ATO-01	Z10004	1.18	5.60	168.00	6,080.00	196.00
ATO-01	Z10005	1.14	7.40	232.00	3,890.00	236.00
ATO-01	Z10006	1.19	7.00	407.00	5,410.00	495.00
ATO-01	Z10007	1.95	7.80	637.00	4,450.00	549.00
ATO-01	Z10008	1.84	8.80	702.00	5,100.00	844.00
ATO-01	Z10009	2.61	11.50	1260.00	11,000.00	1,045.00
ATO-01	Z10010	1.81	10.00	1220.00	2,820.00	1,096.00
ATO-01	Z10011	0.95	4.50	423.00	2,660.00	400.00
ATO-01	Z10012	1.26	5.20	227.00	2,600.00	183.00
ATO-01	Z10013	1.40	7.90	179.00	1,870.00	178.00
ATO-01	Z10014	1.65	10.90	462.00	2,570.00	280.00
ATO-01	Z10015	1.25	8.20	382.00	2,260.00	227.00
ATO-01	Z10016	1.51	7.80	495.00	2,780.00	295.00
ATO-01	Z10017	1.07	5.20	480.00	1,100.00	283.00
ATO-01	Z10018	1.77	10.10	779.00	5,670.00	522.00
ATO-01	Z10019	1.58	9.20	490.00	5,870.00	394.00

As can be seen, even though the amount of copper in the low-grade gold ore is high, it is economically inadequate. Moreover, during the process of leaching the ore with cyanide, copper interacts with cyanide, and mono-, di-, and tri-copper cyanide compounds are formed.



Pregnant solutions for cyanide leaching are often contaminated by impure metals such as copper (Marsden and House, 2006). Cyanide also forms complexes with these impure metals solubilized from host/gangue minerals, increasing the consumption of cyanide in leaching.

For example, under typical cyanide leaching conditions, copper dominantly presents in cuprous form (Cu^+), which readily forms cyano-complexes of $\text{Cu}(\text{CN})_2^-$, $\text{Cu}(\text{CN})_3^{2-}$ and $\text{Cu}(\text{CN})_4^{3-}$ depending on the concentration of cyanide and copper, pH, and temperature (Xie et al., 2013). Metal-cyanide complexes are classified, based on their stability constants, as strong ($\log K > 30$) and weak ($\log K \leq 30$) complexes (Table 2) (Van der Merwe and Breuer, 2013).

Table 2: Weak and strong metal-cyanide complexes

Reaction equation	Stability constant
Strong acid dissociable cyanides (SAD)	
$\text{Co}^{3+} + 6\text{CN}^- \rightarrow \text{Co}(\text{CN})_6^{3-}$	$\log \beta_6 = 64.0$
$\text{Fe}^{3+} + 6\text{CN}^- \rightarrow \text{Fe}(\text{CN})_6^{3-}$	$\log \beta_6 = 43.6$
$\text{Fe}^{2+} + 6\text{CN}^- \rightarrow \text{Fe}(\text{CN})_6^{4-}$	$\log \beta_6 = 35.4$
$\text{Au}^+ + 2\text{CN}^- \rightarrow \text{Au}(\text{CN})_2^-$	$\log \beta_2 = 38.8$
Weak acid dissociable cyanides (WAD)	
$\text{Ni}^{2+} + 4\text{CN}^- \rightarrow \text{Ni}(\text{CN})_4^{2-}$	$\log \beta_4 = 30.22$
$\text{Cu}^+ + 4\text{CN}^- \rightarrow \text{Cu}(\text{CN})_4^{3-}$	$\log \beta_4 = 23.10$
$\text{Cu}^+ + 3\text{CN}^- \rightarrow \text{Cu}(\text{CN})_3^{2-}$	$\log \beta_3 = 21.66$
$\text{Ag}^+ + 2\text{CN}^- \rightarrow \text{Ag}(\text{CN})_2^-$	$\log \beta_2 = 20.48$
$\text{Cu}^+ + 2\text{CN}^- \rightarrow \text{Cu}(\text{CN})_2^-$	$\log \beta_2 = 16.26$
$\text{Zn}^{2+} + 3\text{CN}^- \rightarrow \text{Zn}(\text{CN})_3^-$	$\log \beta_3 = 16.05$
$\text{Zn}^{2+} + 4\text{CN}^- \rightarrow \text{Zn}(\text{CN})_4^{2-}$	$\log \beta_4 = 19.62$
$\text{Cd}^{2+} + 4\text{CN}^- \rightarrow \text{Cd}(\text{CN})_4^{2-}$	$\log \beta_4 = 17.92$
Free cyanide (CN^-, HCN)	
$\text{H}^+ + \text{CN}^- \rightarrow \text{H}(\text{CN})$	(pKa 9.3 at 20°C)

The ratio of weak acid dissociable (WAD)/weak acid cyanide/cyanide versus Cu glycinate in the system depends on the redox cycling between cuprous (Cu(I)) copper and cupric (Cu (II)) copper.

Oraby and Eksteen (2016) demonstrated that the slow leaching rate of glycine can be counteracted by adding small amounts of copper and cyanide (as cuprous-cyanide complex) to the glycine solution, resulting in leach rates as much as five times higher than those of cyanide-only leaching. In all cases where cyanide is present, it is at starvation levels. That is, the cyanide is utterly insufficient to dissolve cyanide-soluble copper minerals, and free cyanide is not measurable at the end of the leaching process, although low levels of WAD cyanide may remain. The use of small amounts of cyanide is usually not problematic as environmental effects are minimized, safety for workers is maximized, and operating costs are reduced significantly.

In addition to carbon, its elemental composition, which to a large extent depends on the source raw material, comprises hydrogen, nitrogen, sulfur, and oxygen. Active carbons have a tridisperse microcrystalline structure comprising pores of varying sizes classified as: micropores (<2 nm), mesopores (2–50 nm), and macropores (>50 nm). Macropores found on the outer surface of the active carbon particles act as a gateway for adsorbate molecules to pores in the innermost part of the active carbon. Mesopores, also known as transitional pores, branch directly off macropores and their function is to channel the adsorbate into the micropores.

Micropores, which make up about 95% of the total surface area of the active carbon, largely affect the adsorption capacity of a given active carbon. Most activated carbon adsorbents that are used commercially have a specific surface area in the order of 800 to 1,500 m²/g. The adsorption efficiency of active carbons is also determined by the chemical structure of the carbon's surface.

Maintaining a low free cyanide concentration increased the carbon's selectivity of gold over copper. Increasing the CN:Cu molar ratio from 1:1 (i.e. 123 ppm cyanide) to 2.5:1 (i.e., 476.3 ppm cyanide) reduced the gold loading capacity by half due to the increased adsorption competition of CN⁻ ions and copper. This is related to the presence of the WAD cyanide $Cu(CN)_2^-$. It is better to minimize the WAD cyanide in glycine-cyanide-copper in order to have higher gold adsorption. This may be done by sulfide precipitation, solvent extraction, or ion exchange.

Methodology and discussion

Copper compound deactivation

In order to stop the copper from being adsorbed into activated carbon and reducing gold loading, the cyanide content of the solution was increased from 18 ppm to 400 ppm, and adsorption tests were carried out for varying amounts of time on each of the different mixing times. As shown in Table 3, additional cyanide significantly decreased the copper adsorption in activated carbon and enhanced the gold content.

Table 3: Copper absorption in pregnant cyanide solution

	Pregnant solution cyanide content, ppm	Absorption time, min	Feed solution total Cu, ppm	After absorption solution total Cu, ppm	Cu absorption, %
Bottle roll absorption test	18	5	310	250	19.35
	50	10	280	233	16.78
	100	15	250	229	8.4
	250	25	280	277	1.07
	300	30	170	170	0.0
	400	40	280	280	0.0

Real life practice

Beginning in March of 2022, the processing plant was fed with cyanide. When the cyanide content was low, copper adsorption was very high and gold adsorption was very low. After adding cyanide into the cycle solution in March, copper adsorption decreased, and gold adsorption increased significantly, as shown in Table 4.

Table 4: Metal adsorption in activated carbon in the processing plant

Strip no.	Pregnant solution cyanide	Load carbon, Au	Load carbon, Cu
	ppm	ppm	ppm
130	7.81	908.2	133,231
135	5.2	711	148,860
139	5.2	679.8	107,328
175	250	4,670	31,316
179	270	2013	15,900
180	210	3,103	17,150
181	290	3,010	16,129
182	225	2,330	16,122

Date	Carbon grade			Cyanide content of pregnant solution, ppm
	Au	Ag	Cu	
1 Feb 2022	711.0	3,811.7	148,860.8	0
4 Feb 2022	652.5	4,601.9	66,892.1	0
7 Feb 22	594.2	2,985.3	91,923.9	0
11 Feb 22	679.8	3,178.9	107,328.6	0
13 Feb 22	649.5	3,610.3	120,996.7	0
16 Feb 22	655.1	3,271.8	124,315.4	0
21 Feb 22	549.8	3,695.8	75,558.4	0
10 Mar 22	5,270.1	9,173.9	9,153.6	250
13 Mar 22	3,476.5	7,045.6	16,210.0	250
16 Mar 22	2,295.9	6,116.1	19,989.8	250
19 Mar 22	1,638.7	4,204.7	20,555.8	250
1 Apr 22	2,396.2	5,359.2	23,911.5	250
3 Apr 22	2,134.1	5,795.7	26,864.2	250
05 Apr 22	1,865.0	6,338.3	23,958.0	250

Removing copper from the waste acid solution

Copper and silver in the gold concentrate was dissolved in nitric acid during the digestion stage to separate the gold. After silver was recovered by precipitation with the help of NaCl to form silver chloride, copper remained in the nitric acid solution. The metal content is presented in Table 5.

Table 5: Metal content of waste acid from digestion

SAMPLE ID	Au	Cu
	ppm	ppm
	Au-AA44	Cu-OG43n
Sample 1	4.47	121,763.1
Sample 2	2.44	108,517.7

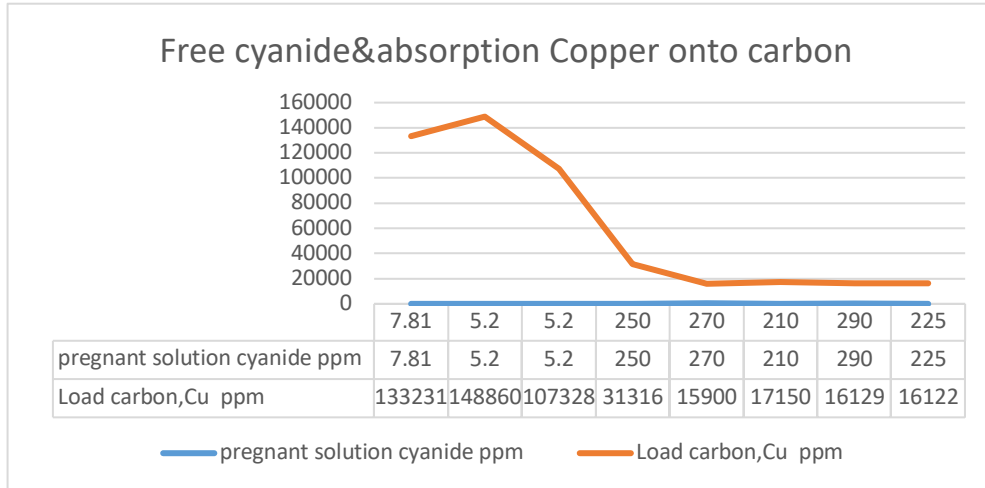


Figure 1: Free cyanide and adsorption of copper onto carbon

On average, the sample solutions produced approximately 1,500 kg of 115,140 ppm copper solution from every digestion stage, which was then poured into the mines barren pond. While circulating the high copper content, the solution was absorbed into activated carbon, which obstructed the gold absorption.

Therefore, there was a need to separate copper from the waste acid solution at a low cost and without installing new equipment.

Five millilitres of copper-containing solution was taken for comparison, and 1 gram of caustic soda was added to the first glass of solution. After mixing, the solution to which caustic soda was added turned deep blue with pure water on the top, meaning that it was fully separated from copper.



Figure 2: Caustic soda added to the solution



Figure 3: Precipitated copper sludge being filtered



Figure 4: Smelted copper out of waste solution

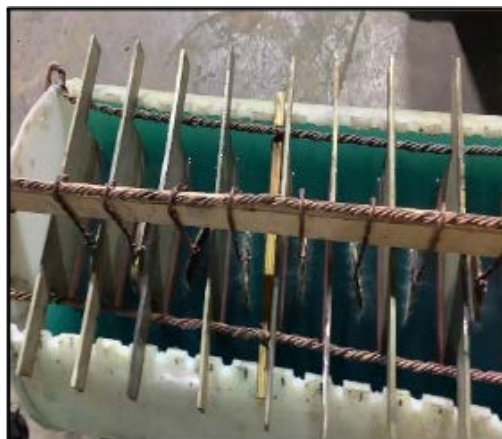


Figure 5: Ongoing electrolysis



Figure 6: Refined gold powder



Figure 7: Before and after comparison of refined bar

Copper removal was tested using a method in our actual process, and it purified the solution until its copper concentration reached 3 ppm. The precipitated copper was dried and smelted into pure copper.

Refining of high-copper-content gold ore

Two mini-scale electrowinning cells were built with a volume of 40 to 50 litres each. We prepared 12 pieces of 20×20 cm stainless steel board as cathode to carry out the experiment while the plant's stripping process was undertaken, in order to monitor and adjust the test process precisely. For instance, we adjusted the cathode size corresponding to the alloy bar size. The bars were supposed to be used as an anode. However, it was too thick for electrolysis; therefore, we re-smelted and cast them as 2 kg bars.

Welding apparatus was connected to the EW cell's anode and a cathode with doubled copper wire in order to supply electric current.

Copper electrolysis

We hung three alloy bars as an anode, and 12×12 cm stainless-steel boards as a cathode in the prepared

electrowinning cells.

Each EW cell was filled with 40 to 50 litres of water, 4 litres of nitric acid, 2.5 litres of ~15% copper nitrate solution, and was supplied with a 42 A electric current. While the process was being carried out simultaneously in the 2 EW cells, the chemicals were added to keep electrolysis proceeding effectively. Also, the operational solution was replaced with a new solution every other day, so that it would not become contaminated and slow down the process. The old solution had to be filtered to catch any gold powder.

During electrolysis, the alloy bars eroded by acid and electric current due to copper transfer into cathode, and gold became a compact powder stuck on the bar surface. Then, the gold powder covering the alloy was scraped in order to speed up the process. The alloy bars were scraped twice a day. The bars were hung like hooks, to make it easier. The electrolysis process lasted for 13 days in order to completely extract the gold inside the bars.

- *Gold cleaning*: the extracted gold powder was washed in nitric acid twice to remove trace copper. This was followed by washing in plenty of water to neutralize its acidic condition.
- *Smelting*: the fine gold powder was dried in a calcine oven for five hours and smelted.

As a result, a total of 14.38 kg of 4 pcs fine gold bars were produced from the high copper content alloy bars. It is calculated that the initial fineness of the bars was 314°.

Conclusions

For this project, research on removing the copper cyanide compounds that are formed during the heap leaching of low grade oxidized ores was carried out. The following conclusions were drawn.

The pregnant cyanide leach solutions of complex ores contain impure metals that form cyanide complexes. A certain level of free cyanide is required to be present in leach solutions for the efficient leaching of gold. Therefore, the content of free cyanide in the solution was adjusted to between 50 to 400 ppm. The most suitable cyanide content is >250 ppm, when the copper cyanide in the solution is contained in the pond in the form of a solution that does not adsorb on the activated carbon.

If this problem continues for a long time, adverse impacts such as cyanide consumption increase. Moreover, due to the increase of pollution in the solution ponds, the leaching process may be slowed down.

If the leaching process slows down, it is necessary to either change the solution in the solution ponds, or install a filter. When the copper amount is <300 to 500 ppm and the pH is high (pH>12.5), precipitating the copper and cyanide is the most efficient solution. But, it is clear that is not the case for the Altan Tsagaan-Ovoo mine project.

Also, the most economical solution might be to accumulate the copper-rich solution in which the desorption was done, to prevent the copper amount from increasing in the solution pond to the tailing storage pond.

Selective leaching of gold over copper from a copper–gold concentrate containing significant amounts of cyanide soluble copper has been achieved using cyanide solution and caustic soda as a pH modifier. The results showed that gold dissolution can be enhanced, and cyanide consumption can be reduced, if the leaching parameters are optimized. The important leaching conditions include cyanide concentration, CN/reactive copper ratio, and the pH of the leach solution.

Cyanidation is the dominant method of recovering gold from ores. In recovering gold from copper-containing gold ores by cyanidation, some copper minerals readily dissolve in cyanide. These can have a detrimental effect on the process efficiency and economics due to high cyanide consumption, reduced gold leach rates, and poor gold recovery.

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