Role of hydrogen ions in standard and activation heap leaching of gold

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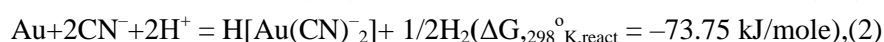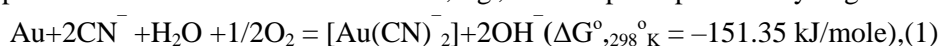
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Abstract. The role of hydrogen ions in activation heap leaching of gold from rebellious ore has been studied, which has allowed enhancing gold recovery. The author puts forward a gold leaching circuit with the use of activated oxygen-saturated solutions acidified to pH = 6–9.
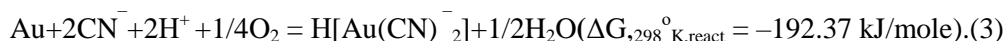
One of the causes of reduction in old extraction by cyanide heap leaching is the absence of theoretical evidence on mechanisms of intracrystalline processes.

Hydrogen ions in monomolecular surface layer of crystalline lattice possess comparatively high energy of bond with mineral atoms (of the order of 40–120 kJ/mole) and, being very small in size, can actively participate in intracrystalline processes. In this respect, oxidizing properties of hydrogen ions can prevail over oxidizing properties of oxygen. The introduced hydrogen ions have an effect on atoms (ions) in deep layers of crystalline lattice either by means of sequential transmission of impulses between internal layers or by way of diffusion inward the lattice, through interstitial sites, up to reaching sites of internal layers [1]. In activation cyanide leaching of rebellious gold from ore, an important part belongs to water as the main source of hydrogen ions. A one-time source of hydrogen may be acid; at the same time, after equilibrium exchange processes of electrolytic dissociation and hydrolysis, it is difficult to stabilize concentration of hydrogen ions)(pH) without secondary electrochemical treatment of cycling solution in anode chamber of diaphragm cell. The secondary intercrystalline processes conditioned by interaction between hydrogen ions, cyanide ions, hydroxyl radicals and lattice atoms may induce hypermobility of the lattice components, including gold. When hydrogen ions come to the surface of an electroconductive component of ore (iron sulfide crystal) and accept electrons from gold atoms, the generated gold ions in the lattice become more mobile or active as a consequence of charging and size reduction. In case that disjoining action of electrolytic solution enables cyanide ions to flow in micro-channels or structural damage and to reach gold surface, the nascent god cyanide complexes $[Au(CN)_2]^-$, structurally linear and extremely stable, are forced by diffusion directed to the periphery of crystal to leave the crystal and pass into solution. In the studies performed by the present paper author, water pH was adjusted by acidification of solution and aqueous medium was activated by electrolysis.

These studies were aimed at enhancement of gold extraction by rapid heap leaching from low-sulfide ore using activated oxygen-saturated solutions with hydrogen ions involved.

The bottom line of the studies is the new approach to gold cyanidation, when classical cyanidation is likely to be accompanied with the other chemical reactions, e.g., with the participation of hydrogen ions [2]

$$Au + 2CN^- + H_2O + 1/2O_2 = [Au(CN)_2^-] + 2OH^- \quad (\Delta G^o_{,298^oK} = -151.35 \text{ kJ/mole}), (1)$$

$$Au + 2CN^- + 2H^+ = H[Au(CN)_2^-] + 1/2H_2 \quad (\Delta G_{,298^oK,react} = -73.75 \text{ kJ/mole}), (2)$$

$$Au+2CN^- +2H^+ +1/4O_2 = H[Au(CN)^-_2]+1/2H_2O(\Delta G,^o_{298 K,react} = -192.37 \text{ kJ/mole}).(3)$$

In this case, hydrogen ions initiate gold cyanidation in solution: gold leaching becomes feasible without oxygen (reaction 2), while when oxygen is present, more expectable is gold cyanidation with the release of water rather than hydroxide ion (reaction 3, $\Delta G_{297}^o{}_{K,react} = -192.37$ kJ/mole).

In accordance with Figure 1, at pH = 9.35 concentration of C_{CN^-}-ions is comparable with C_{HCN} [3]. When pH $\leq$ 9.35 concentration of C_{H^+}-ions grows and gold cyanidation rate should increase; when pH > 12, cyanidation of gold is terminated.
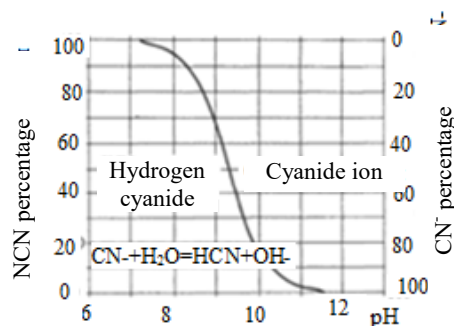

Figure 1. Influence of pH on percentage of HCN and CN- in aqueous solution.

Table 1 gives data on gold cyanidation with hydrogen ions and without oxygen. Based on these data, it has experimentally been proved that gold and hydrogen ions interact according to reaction 2 as the residual quantity of dissolved oxygen after high-pure argon blow of the solution is 10 times less than it should be in accordance with stoichiometry of cyanidation reaction 1 as indicated in the findings of the Hydrology Department Laboratory at the Transbaikalia State University. Incidentally, on the surface of gold chips or gold webs, gas bubbles 1–2 mm in size were visually observed. The calculations showed that the gas could be hydrogen as its mole fraction conformed with the mole fraction of gold in dissolution according to reaction 2 and made 0.2.10–4 moles.

Table 1. Influence of pH of aqueous cyanide solution of gold cyanidation in argon medium.

No.	C_{NaCN}, g/l	Introduced HCN, ml	Introduced H_2SO_4, g/l	T, days	pH	Gold weight, mg	After-test gold weight, mg	Comments
1	1	–	–	3	11	553.8	553.8	Gold slab, $S = 1$ cm^2, $t = 26^o$C,
2	1	–	–	3	11	11	11	Gold web, $t = 25^o$C, argon
3	1	–	–	3	11	7	7	Gold chips, particle size < 0.02 mm, $t = 24^o$C, argon
4	1	–	2	3	6	10.4	6.5	Gold web, $t = 22^o$C, argon
5	–	2	–	3	7	10.2	8.1	Gold chips, particle size < 0.02 mm, $t = 17^o$C, argon
6	–	2	–	4	7	9.1	5.3	Gold web, $t = 17^o$C, $t = 17^o$C, argon
7	–	2	–	3	7	10.2	9.5	Gold web, $t = 17^o$C, air

Table 2. Initial conditions of ore agglomeration for subsequent standard-circuit gold leaching.

Q of dehumidified ore, kg	Fragmentation size, mm	Absorption of NaCN, kg/t	Cement consumed in agglomeration, kg/t	Lime consumed in agglomeration, kg/t	Agglomeration solution, l	C_{NaCN} in agglomeration, g/l	Vday solution consumed for spraying, l	Ore gold content, mg
46.32	10	0.07	0.12	0.06	0.75	0.35	6.8	69.48

Experimental leaching of gold was carried out on crushed rebellious low-sulfide ore extracted from an open pit depth of 150 m in accordance with the standard leaching circuit and with activation of leaching solution at pH = 6–9. The tests used percolation filters with the following dimensions: $h = 1.15$ m; $d_{pf} = 0.208$ mm, $S_{pf} = 0.03396$ m^2. The calculated initial parameters for ore agglomeration and standard gold leaching circuit are given in Table 2.

The standard gold leaching results are reported in Table 3.

Table 3. Results of drop gold leaching in percolation filter at pH = 10.5.

T, days	V_{day} of pregnant solution, l	pH of pregnant solution	CAu in pregnant solution, mg/l	C_{NaCN} in pregnant solution, mg/l	ΔqAu days, mg	$\sum q$Au after percolation, mg	X Au leaching rate, %	Extra cyanide input, g	NaCN in cycling solution, g
1	5.45	12	1.31	0.15	7.14	7.1	10.2	2.1	0.81
2	6.38	8	0.64	0.15	4.08	11.2	16.1	2.1	0.95
3	6.8	8	0.64	0.15	4.35	15.6	22.4	2.1	1.02
4	6.2	8	0.37	0.15	2.29	17.7	25.7	2.1	0.93
5	6.9	9	0.36	0.15	2.48	20.4	29.3	2.1	1.03
6	6.9	7	0.34	0.15	2.35	22.7	32.7	2.1	1.03
7	6.56	8	0.22	0.15	1.44	24.1	34.8	2.1	0.98
8	6.6	9	0.16	0.15	1.06	25.2	36.3	2.1	0.99
9	6.5	6	0.23	0.15	1.50	26.7	38.4	2.1	0.97
10	6.75	6	0.2	0.15	1.35	28.0	40.4	2.1	1.01
11	6.5	6	0.16	0.15	1.04	29.1	41.9	2.1	0.97
12	7.1	6	0.16	0.15	1.14	30.2	43.5	2.1	1.06

Table 4. Initial conditions for ore agglomeration and subsequent activation leaching of gold.

Q of dehumidified ore, kg	Fragmentation size, mm	Cement consumed in agglomeration, kg/t	Lime consumed in agglomeration, kg/t	Agglomeration solution*, l	C_{NaCN} in agglomeration, g/l	NaCN consumed in agglomeration, g/	V of oxygen-saturated solution for spraying, l	Ore gold content, mg
47.29	10	0.12	0.06	0.75	13.5	10.125	4	70.9

*) agglomeration used cyanide solution after electrolytic activation and subsequent saturation with oxygen up to dissolved oxygen content of 33–39 mg/l

Table 5. Results of experimental activation gold leaching.

T, days	V_{day} of pregnant solution, l	pH of pregnant solution NaCN	CAu in pregnant solution, mg/l	CNaCN in pregnant solution, g/l	ΔqAu day, mg	$\sum \Delta q$Au after percolation, mg	X Au leaching rate,
3	3.24	10	1.92	9.5	6.2		8.7
4	2.96	8	1.98	0.22	5.9	12.1	17.0
5	2.72	8	1.87	0.15	5.1	17.1	24.2
6	3.1	9	1.72	0.15	5.4	22.5	31.7
7	2.52	7	1.71	0.15	4.4	26.8	37.7
8	2.6	8	1.7	0.15	4.4	31.2	44.0
9	2.72	9	1.65	0.28	4.5	35.7	50.3
10	2.15	6	1.61	0.2	3.4	39.1	55.2
11	1.9	6	1.62	0.22	3.1	42.2	59.5
12	1.7	6	1.53	0.23	2.6	44.8	63.2

Tables 4 and 5 give the calculated initial parameters for ore agglomeration and activation leaching of gold at pH = 6–9 and the experimental results of the activation gold leaching, respectively.

The experimental gold leaching results are given in graphical form in Figure 2. After having generalized data on standard and activation leaching of gold at pH ranged from 6 to 9, it is possible to draw a conclusion on the efficiency of activation aqueous cyanide solutions by electrolysis and subsequent saturation with oxygen and acidification up to pH = 6–9 in enhancement of gold extraction and in improvement of rapid heap leaching of gold from rebellious ores.
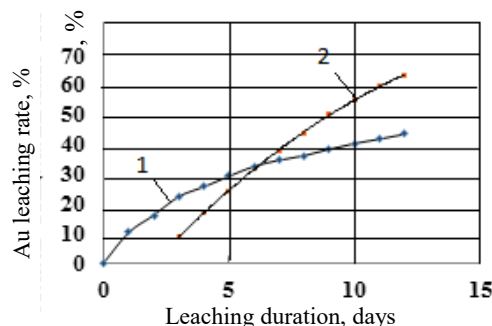

Figure 2. Gold leaching in percolation filter 1 at pH = 10.5 (curve 1) and in percolation filter 2 at pH = 6–9 (curve 2).
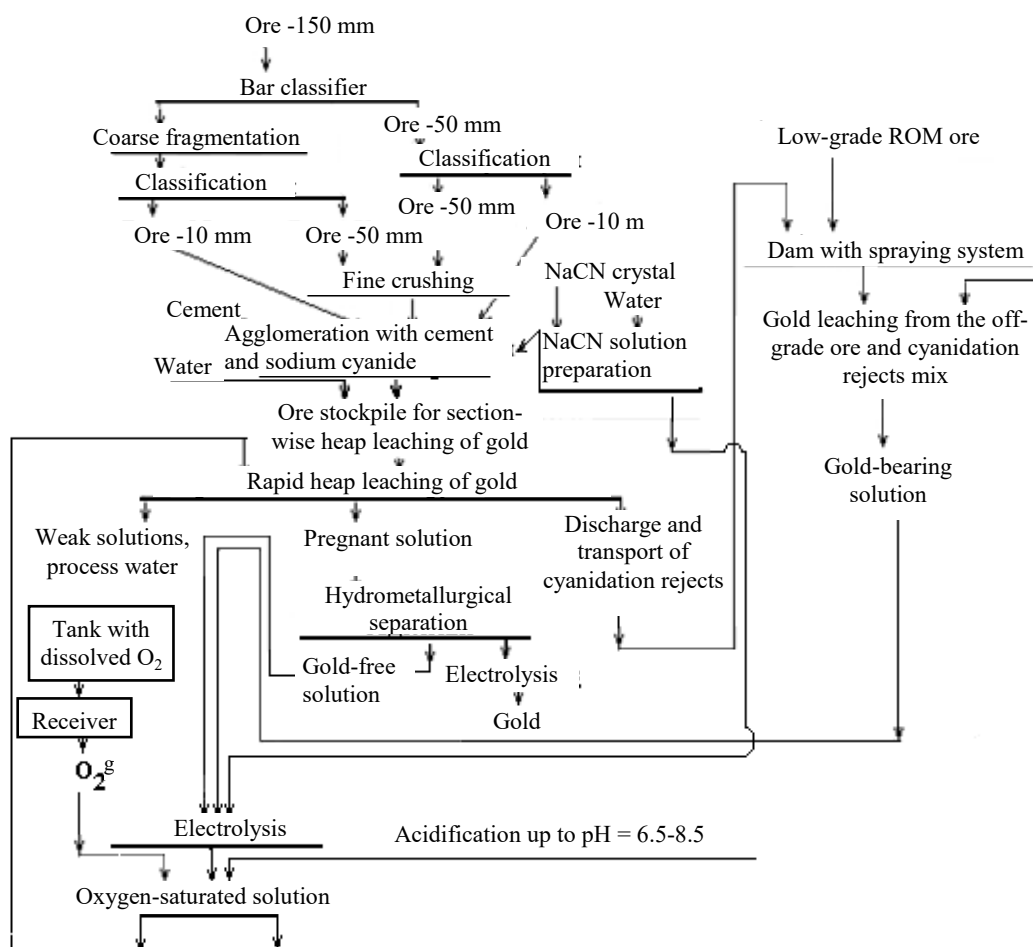

Figure 3. Flow chart of activation leaching of gold.

Based on the data from Tables 3 and 5 and using the equation of kinetics of heap gold leaching [4], the rate of the activation leaching of gold in 20 and 30 days makes 70 and 76%, respectively. In case of the standard circuit of drop heap leaching of gold, the same rate of leaching is likely to be expected in 60 and 90 days.

Then, experiments on gold leaching in cyanide solutions saturated with oxygen and acidified up to pH = 6–9, but without electrolytic activation were carried out. Efficiency of rebellious gold leaching was much higher than in the standard cyanidation circuits but lower by 7–12% than in the circuits with the activated cyanide solutions.

The introduction of the activated solutions after saturation with oxygen and acidification up to pH = 6–9 complicated the rapid heap gold leaching flow chart added with the stage of electrolytic activation of cyanide solution and the stage of acidification of cyanide solution up to (see Figure 3).

Conclusion
The introduction of hydrogen ions in activated and oxygen-saturated solutions with intent the reach the solution pH = 6–9 has a beneficial effect on gold extraction from rebellious low-sulfide ores.

References
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