

# Investigation of gold content in the bio-oxidation process

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**Abstract.** In this study, the process of bio-oxidation of flotation concentrate from the flotation of gold-sulfide ores and sorption cyanidation of the bio-oxidation product were analyzed, and the content of dispersed gold in pyrite, arsenopyrite, and carbonaceous matter was determined. The article also presents the results of laboratory studies on the behavior of gold ions at different stages of leaching, analysis of the gold content in solid samples after acid and alkaline treatment, as well as a semi-quantitative elemental composition. The formation of jarosite minerals was studied at high concentrations of chloride ions and on the surface of pyrite and negatively affects the oxidation of pyrite/arsenopyrite.

## 1 Introduction

The conventional grinding methods fail to liberate the valuable metals enclosed within the sulfide, which explains the unsatisfactory outcomes observed in the direct cyanidation of gold concentrate. Preparation of the gold concentrate before cyanide leaching is necessary. However, existing pretreatment technologies such as oxidation roasting [2], pressure oxidation, and chemical oxidation utilizing various oxidizing agents (ozone, nitric acid) [3] face limitations due to high production expenses and detrimental environmental consequences.

Bioleaching, including bio-oxidation, is regarded as an economically viable and environmentally friendly substitute for conventional extraction methods [4]. It is a viable option for extracting valuable metals from various minerals and waste materials [5,6,7]. Acidophilic bacteria, such as *Acidithiobacillus* spp., which thrive in acidic environments, are commonly found during the bio-oxidation of arsenopyrite. These bacteria possess the capability to oxidize iron and/or sulfur [8].

While the presence of additional metal ions can enhance bacterial proliferation, it can also lead to the accumulation of various secondary byproducts, thereby influencing the mobility of aqueous chemical components [9]. When incorporated into culture media, certain inorganic ions, particularly  $K^+$  and  $NH_4^+$ , facilitate the production of K-jarosite and

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ammoniojarosite. These substances can effectively immobilize metal(loid)s, including arsenic, by means of adsorption or co-precipitation mechanisms [10].

Mine tailings (MTs) refer to waste rocks that are produced during mining activities and can be either fine or coarse-grained. These tailings are typically stored near the mining site, either in the form of solid piles or as the liquid in impounding lakes [11]. However, the continuous accumulation of these tailings poses several challenges. It occupies a substantial amount of land and increases the risk of failure in the reinforcement of impounding lakes or tailings dams. Such failures can lead to significant safety and environmental concerns, including the contamination of surface water, groundwater, and soil [12]. The manner in which mine waste is stored poses a significant and imminent risk to the environment in the vicinity [13]. Jarosites, commonly encountered by-products and effective metal(loid) traps in bioleaching operations, can be solubilized through anaerobic microbial processes that utilize organic matter, hydrogen, or reduced inorganic sulfur compounds as electron donors [14].

The two-stage oxidation process is recommended widely nowadays. However, as a consequence of this process, there is an unavoidable loss of ferric iron resources due to the formation of the associated precipitation product. As an illustration, under varying pH and sulfate conditions, ferric iron can give rise to different substances including jarosite, schwertmannite, goethite, and more [15].

The objectives of the present research are (i) investigation of the behavior of gold ions at different stages of leaching; (ii) analysis of gold content in solid samples after acid and alkali treatment; (iii) learning semi-quantitative elemental composition.

## 2 Materials and methods

The research material was samples of sulfide ores from different stages of bacterial leaching, from ore preparation, enrichment, up to thickening, neutralization, sorption cyanidation and analysis of cyanidation tailings.

Ores from the Kokpatas and Daugiztau (Uzbekistan) quarries are supplied to the technology as feedstock [8].

The following preparatory steps were taken to ready solid phase samples for spectral analysis. Firstly, the liquid phase was separated and filtered. The remaining solid residue was then treated with concentrated nitric acid at a temperature of 600 °C and subsequently dried in an oven for 4 hours.

Afterward, the dried filtrate underwent alkaline treatment using a saturated solution of KOH at a temperature of 60 °C and was again dried in an oven for 4 hours. The resulting solid residue was fired in a muffle furnace at a temperature of 450 °C.

The liquid phase of the samples was analyzed using liquid chromatography, while the solid phase was examined through X-ray diffraction spectral analysis using an ICP-MS-7500 instrument.

## 3 Results

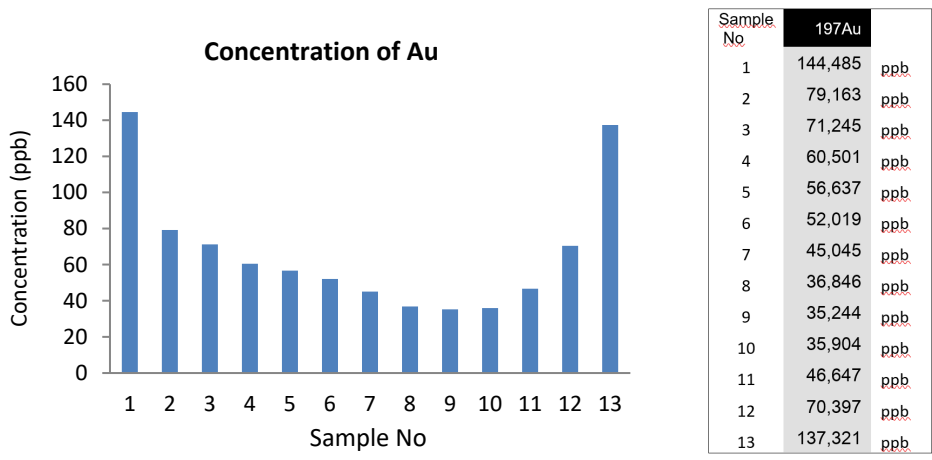
Table 1 shows that all mineral deposits consist mainly of three types of minerals, which include rock-forming, accessory and ore minerals.

**Table 1.** Mineral composition of sulfide ores.

Rock-forming minerals	Content,%	Accessory minerals	Content,%	Ore minerals	Content,%
Quartz and feldspars	22-57	Rutile Ilmenite	0.2-0.7 0.02	Pyrite Arsenopyrite	3.0-9.0 0.1-1.5

Hydromicas, kaolinite, dickite, biotite	25-60	Magnetite	-«-	Antimonite	3
Ankerite, oligonite, siderite, calcite	2-17	Zircon Tourmaline	-«- -«-	Sphalerite Fahlore	0.01 -«-
Carbonaceous matter	0.02-0.2	Moissonite	-«-	Pyrrhotite	-«-
Barite	0.05-0.2	Grenades	-«-	Boulangerite	-«-
		Apatite	-«-	Chalcopyrite	Unit of grain
		Olivine	-«-	Galena	-«-
				Freisbergite	-«-
				Gold	-«-

The bulk are rock-forming minerals, of which hydromicas, kaolinite, dickite and ankerite make up 25-60% of the total mass. In second place in terms of weight content are quartz and feldspars, which make up 22-57% of the mass of the ore.



**Fig. 1.** Behavior of gold ions at different stages of leaching.

The presence of gold ions in the liquid phase (Figure 1), showed that at the very beginning, at the stage of grinding, colloidal gold is released into the solution in an amount of 141 mkg/l. During flotation, part of this gold disappears, leaving only about 80 mkg/l in the solution. Apparently, the gold ions were depressed by some types of flotation reagents passed into the flotation tailings. Subsequently, in the oxidation reactors, the amount of ionic gold decreases in an amount from 60 to 45 mkg/l. The rest of the colloidal gold is washed, passing to the neutralization stage.

From the received samples, the liquid and solid phases were separated and they were analyzed for quality and quantity for the main chemical elements.

From Table 2, we can only conclude that only some gold compounds were exposed to nitric acid. Therefore, in the variants with ore from the classifier and in the flotation concentrate, partial dissolution of gold was noted in the amount of 797.76 and 389.16 mkg/kg. Although the classifier notes the dissolution of a certain amount of gold under the influence of alkali - 389.16.

In the oxidation reactors, a contradictory picture is observed, if 1478.93 mkg/kg was dissolved in the first reactor under the influence of nitric acid, then under the influence of alkali no reliable quantitative values of the dissolution of gold compounds were noted. Only in cyanidation tails and cinder cyanidation tails is dissolution under the action of alkali - 1235.78 and 3784.69 mkg / kg, quantitatively inferior to dissolution with acid - 7287.59 and 39880.71 mkg / kg.

**Table 2.** Results of analyzes of gold content in solid samples after acid and alkali treatment.

Name of options	Samples	Au (ppb)
Top drain classifier	Sample 1 acid	797.76716
	Sample 1 alkali	389.15825
Flotation concentrate	Sample 2 acid	291.86604
	Sample 2 alkali	0
Reactor 1	Sample 3 acid	1478.9281
	Sample 3 alkali	0
Reactor 2	Sample 4 acid	379.42662
	Sample 4 alkali	0
Reactor 3	Sample 5 acid	3327.3969
	Sample 5 alkali	428.06867
Reactor 4	Sample 6 acid	3989.1352
	Sample 6 alkali	0
Reactor 5	Sample 7 acid	5477,7156
	Sample 7 alkali	0
Reactor 6	Sample 8 acid	5964.2433
	Sample 8 alkali	933.98302
Countercurrent decanting unit 1	Sample 9 acid	8387.176
	Sample 9 alkali	1439.8998
Countercurrent decanting unit 2	Sample 10 acid	14313.834
	Sample 10 alkali	0
Nutrition	Sample 11 acid	8250.9392
	Sample 11 alkali	0
Cyanidation tailings	Sample 12 acid	7287.5946
	Sample 12 alkali	1235.7839
Cyanidation tailings cinder	Sample 13 acid	39880.71
	Sample 13 alkali	3784.6911

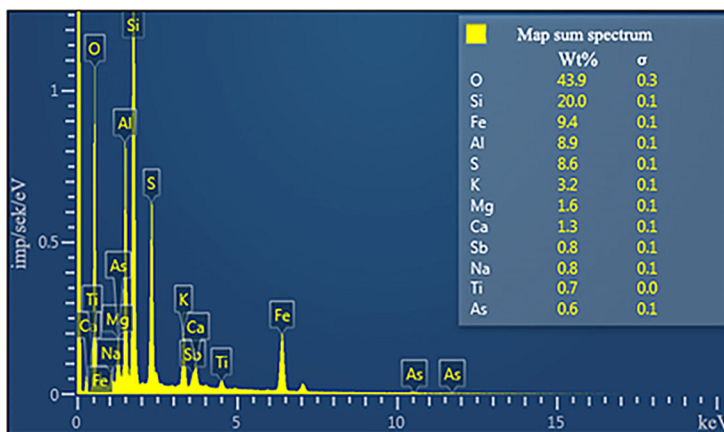
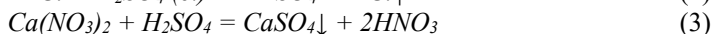
Thus, from Table 2. managed to determine a quantitatively insignificant dissolution of gold in the ore and flotation concentrate. Nitric acid, in all likelihood, carries out the dissolution of gold compounds in intergrowths of quartz, feldspar, and other minerals. Finely disseminated gold of pyrite and arsenopyrite, apparently, is not affected by the action of nitric acid. In reactors about acidification, an ambiguous picture of the dissolution of gold under the action of nitric acid and caustic potassium was noted. On countercurrent decantation 1,

the maximum dissolution of gold by alkali was noted in comparison with acid, and the effect of acid is not observed.

Different nutrients are used in the process. Their consumption and quantities were shown in Table 3.

**Table 3.** Preparation and dosing of the nutrient mixture for production environments.

Name of nutrients	Consumption of nutrients kg/t conc.	Reagents containing nutrients	Quantity, kg/t conc.	Quantity, t/day.
N	1.7	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	6.93	7.408
P	0.3	(NH <sub>4</sub> ) <sub>2</sub> HPO <sub>4</sub>	1.33	1.422
K	0.9	K <sub>2</sub> SO <sub>4</sub>	2.10	2.245
Overall:	2.9		10.365	11.075



**Fig. 2.** The semi-quantitative elemental composition obtained from the surface of sample and the corresponding energy-dispersive spectrum.

Analysis of the energy-dispersive spectrum (Figure 2) shows that the sample consists mainly of oxygen - 43.9%, silicon - 20.0%, iron - 9.4%, aluminum - 8.9%, sulfur - 8.6, arsenic - 0.6%, and other elements.

### 4 Conclusion

In this study, the behavior of gold ions at different stages of leaching, analysis of gold content in solid samples after acid and alkali treatment, and semi-quantitative elemental composition were analyzed. Preparation and dosing of the nutrient mixture for production environments were studied.

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