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Extraction of Gold From Boulangerite Ore Using Sodium Cyanide

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Abstract

Present study focuses over the extraction of gold via sodium cyanide (NaCN) from boulangerite ore. Since the presence of antimony hinders the extraction of gold by cyanidation therefore, the ore was first treated with sodium sulphide (Na_2S) and sodium hydroxide (NaOH) to remove/minimize the antimony content. Gold extraction via cyanidation was then studied for different parameters including concentration of NaCN, time effect and influence of temperature on leaching of gold. It was observed that extraction of gold increases with increase in concentration of NaCN and ore amount. Maximum leaching of gold (52.89 - 76.53 %) was carried out at 80°C, 100 minutes leaching time, 300 rpm and a pH level of 10.5.

Keywords: *extraction, sodium cyanide, boulangerite ore, hydrometallurgy*

1. Introduction:

Since 1890 cyanide has been widely used for the extraction of gold from its ores and concentrates through hydrometallurgical processes. Although there are many difficulties while using hazardous cyanide, however no other efficient and economically viable alternative process has yet been proven to exist [1]. In cyanidation method, the cyanide solution (NaCN) is added to distilled water and grinded ore to oxidize and chemically separate gold particles from its ore. Gold particles from its ores are leached via sodium cyanide according to Elsener's equation [2].

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

Karimi et al., [3] tested cyanidation for two different gold deposits, one contained 10.5 ppm gold and another 2.5 ppm. Cyanidation tests conducted at pH 9.5 - 12 showed the highest recoveries of 94.91% at pH 11 and 92.5% at pH 10.5. Deschenes and Wallingford ***[4]*** investigated a number of leaching parameters ***i.e.*** particle size of ore, concentration of cyanide, adjustment of suitable pH value and use of different amount of oxygen and lead nitrate for the recovery of gold from pyrrhotite ore. They observed 96.1% extraction of gold at the cost of 1.04 kg/t cyanide consumed in 24 hours. Prud'homme and Deschenes [5] reported 98% gold extraction at 1.85 kg/t of cyanide consumption in presence of lead nitrate.

Boulangerite ore also lso called lead antimony sulfide ($Pb_5Sb_4S_{11}$) is a member of sulfosalt with a more general formula of ($A_mB_nS_p$), where A represents a metal (Cu, Pb, Ag, Fe), B represent semi-metals (As, Sb, Bi) and S represents sulfur. Sulfosalt are the segment of sulfide mineral class with antimony acting as a metal rather non-metal,

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and is bounded with sulfur. Boulangerite forms a dense, hairy inclusion within other crystals like calcite and quartz. The name of Boulangerite ore was given after a French mining engineer Charles Louis Boulanger in 1837 [6].

Present study focus over the characterization of boulangerite ore, removal of antimony from the ore and optimization of cyanidation parameters for extraction of gold from boulangerite ore containing traces of gold (15 ppm). Due to the presence of antimony acidic leaching was performed to minimize/remove its content in the ore. After minimizing the antimony content the ore was subjected to cyanidation and the effect of time, temperature and cyanide concentration was studied.

2. Materials And Methods:

Boulangerite ($Pb_5Sb_4S_{11}$) ore was collected from Shishy valley Chitral (35.84°N:71.78°E), Khyber Pakhtunkhwa, Pakistan. Semi-quantitative EDS detected the presence of 52.43 wt% Pb, 24.85 wt% Sb, 19.76 wt% S, 1.51 wt% Cu and traces of Au (15 ppm) in as-mined boulangerite ore sieved through a 200 mesh at Materials Research Laboratory (MRL), University of Peshawar.

The leaching experiments were carried out in a fume hood (LFH-120 SCI, LabTech). 3.0 g of weighed dried sample was placed in a 500 mL glass beaker. 3 grams of Boulangerite ore (200 mesh) was added to 10ml distilled water in a 50ml beaker. pH of solution was adjusted at 10.5 by adding 0.05g of lime. After pH adjustment, 0.2g sodium cyanide (NaCN) was added and the mixture solution was stirred at temperature of 60 °C at a speed of 300 rpm by an electromagnetic stirrer with a Teflon coated stirring bar and a LED indicator showing the stirring speed. Aqueous samples were prepared in order to investigate the effect of various parameters i.e. leaching time, temperature and concentration of cyanide. All the samples were analyzed for gold content using an atomic absorption spectrometer (AAS 700, Perkin Elmer, USA).

The percentage of gold extraction from Boulangerite ore can be obtained using the following formula

Gold extraction % = $b \times \frac{C}{A} \times 100$

B = amount of gold leached from ore

C = amount of filtrate

A = amount of gold present in the as mined ore

X-rays diffraction (XRD) data were recorded at room temperature using a JEOL JDX-3532 X-ray diffractometer, operating at 40 kV and 30 mA, with Cu K radiation (~0.154 nm. Scanning electron microscope (SEM) images of chemically etched samples were recorded using a JEOL JSM5910 SEM, operating at 30 keV. Semi-quantitative energy dispersive X-ray electron spectroscopy (EDS) data was collected using an INCA200 EDS detector (Oxford instruments, UK), connected with a JEOL-JSM5910 SEM.

3. Result And Discussions:

3.1 Characterization of As-mined Boulangerite Ore:

Figure 1 shows the X-rays diffraction pattern (XRD) pattern recorded for as-mined Boulangerite ore ($Pb_5Sb_4S_{11}$) at room temperature. The d-values and relative intensities of the sample related to the major XRD peak (represented as A) matched PDF # 42-1407 for Boulangerite ore ($Pb_5Sb_4S_{11}$) showing it as the major phase in the sample that was examined. In the XRD pattern some minor peaks were observed to be matching with PDF # 12-381 for Antimony Sulfide (Sb_2S_5) showing it as a secondary/minor phase in the sample.

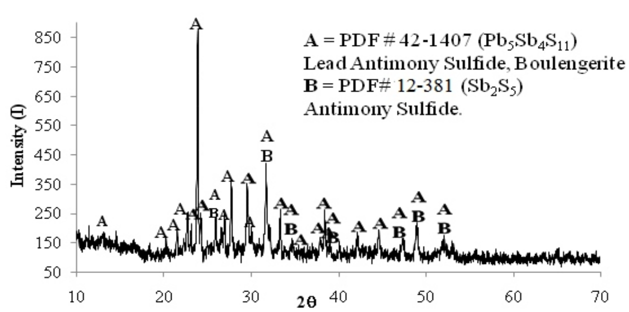
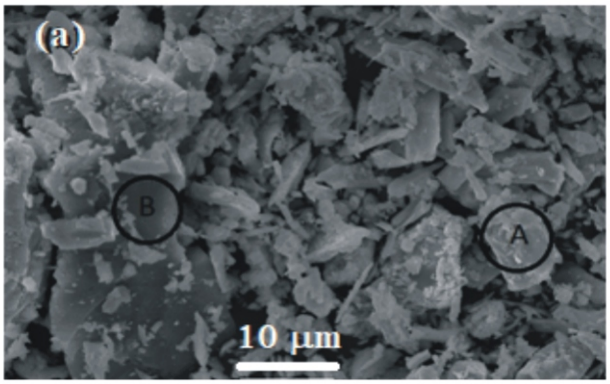


Figure 1: XRD patterns of As-mined Boulangerite o re showing the presence of Boulangerite and Antimony Sulfide phases labeled as A and B respectively.

Figure 2 show the secondary electron image (SEI) of as-mined Boulangerite ore ($Pb_5Sb_{11}S_4$). Two different types of morphologies i.e. polyhedron like and rod (needle) were identified. The grains are inhomogeneously distributed and are randomly oriented. The size of polyhedron like grains ranges in 10-30m.

The varying elemental concentration of the grains marked as A, B, C and D in Figure 2 is shown in the Table 1. These grains are separated by distinct and sharp boundaries.



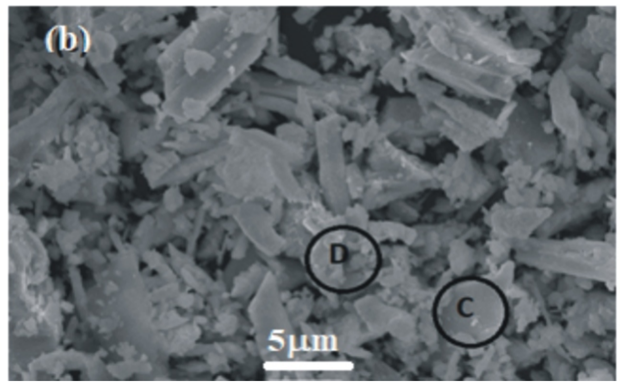


Figure 2 (a-b): Secondary electron image (SEI) of as-mined Boulangerite ore powder showing random distribution of polyhedron and rod like grains.

Table 1: EDS analysis of various micro-regions/grains in as-mined Boulangerite ore indicated by symbols A, B, C and D.

Micro Regions	Elements (wt. %)		
	Pb	Sb	S
Gross	48.18	30.84	20.98
A	53.66	25.90	20.44
B	13.56	81.84	4.60
C	51.70	28.37	19.93
D	50.74	29.51	19.75

3.2 Removal Of Antimony From Boulangerite Ore:

Figure 3 shows SEI of the boulangerite ore after removal of antimony by using NaOH and Na_2S. The microstructure of these samples comprised a random distribution of grains /agglomerates with three different type of morphologies i.e. agglomerates of fine grains “A”, elongated sharp-edged grains “B” and irregular polyhedral grains “C”.

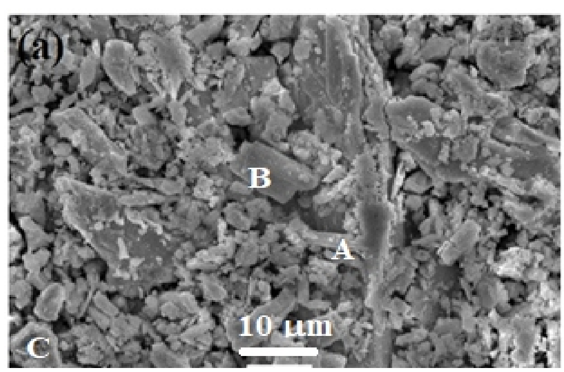


Figure 3: SEI of residual Boulangerite ore powder (200 mesh size) after removal of Antimony, showing grains / agglomerates of different morphologies.

The dimensions of the elongated grains were in the range of 5-10m where as the dimensions of the polyhedral grains were from 5-15m and the micro-regions comprising agglomerates were 15-30m in size. The varying elemental concentration of the grains / micro-regions marked as A, B and C is given in Table 2.

Table 2: Elemental concentration of different grains / micro-regions labeled as A, B and C in Figure 3.

Micro-Region	Elemental concentration (wt%)			
	S	Sb	Au	Pb
Gross	17.39	6.35	2.69	73.57
A	16.92	5.29	2.32	75.47
B	17.75	6.53	2.30	73.42
C	16.93	5.97	2.53	74.57

3.3 Effect Of Leaching Time On Extraction Of Gold:

To find out the best cyanidation time, leaching tests were conducted from 40 100 minutes with an increment of 20 minutes. Samples obtained after filtration were analyzed for gold content. The results presented in Figure 4 shows the effect of leaching time on extraction of gold at 200 mesh particles size. It shows that extraction of gold increased from 52.89 to 53.31 % by increasing leaching time from 40 to 100 minutes. It shows linear behavior after 60 minutes onward. Therefore maximum leaching of gold was observed at 100 minutes. The increase of gold extraction with time is due to the loss in mass of sample, treating the sample for more time the maximum gold extraction will be obtained. Table 3 shows various parameters set for the gold extraction.

Table 3: Effect of leaching time on extraction of gold from Boulangerite ore.

S. No	Ore Amount (gm)	Sodium Cyanide (gm)	Distilled water (ml)	Temp (C)	Particle Size (mesh)	Time (mins)	RPM	Au % Extraction
1	3	0.2	10	60	200	40	300	52.89
2	3	0.2	10	60	200	60	300	52.91
3	3	0.2	10	60	200	80	300	53.13
4	3	0.2	10	60	200	100	300	53.31

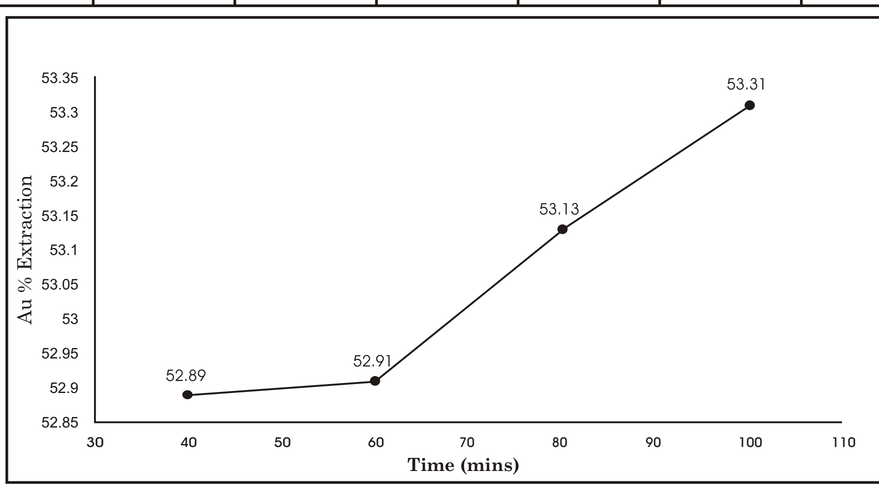


Figure 4: Effect of leaching time on % yield of gold from Boulangerite ore, indicating an increase in gold extraction with increase in leaching time.

3.4 Effect Of Temperature On Gold Recovery From Boulangerite Ore:

Figure 5 show the effect of temperature versus percent of the recovered gold from Boulangerite ore. It was noted that the amount of gold recovery increases for temperature 60 - 80 and then decreased over a zigzag pattern. The effect of temperature on the weight % of the recovered gold is not very common in the literature however; a temperature range of 75-85 ^{0}C has been reported [7]. Above optimum temperature the graph decreases due to the complex nature of Sodium cyanide, it seems to be justified due to the volatile nature of NaCN [8]. The parameters at which the results obtained are summarized in Table 4.

Table 4: Effect of temperature on extraction of gold from Boulangerite ore.

S. No	Ore Amount (gm)	Sodium Cyanide (gm)	Distilled water (ml)	Temp (C)	Particle Size (mesh)	Time (mins)	RPM	Au % Extraction
1	3	0.2	10	60	200	60	300	52.90
2	3	0.2	10	80	200	60	300	53.48
3	3	0.2	10	100	200	60	300	53.15
4	3	0.2	10	120	200	60	300	53.20

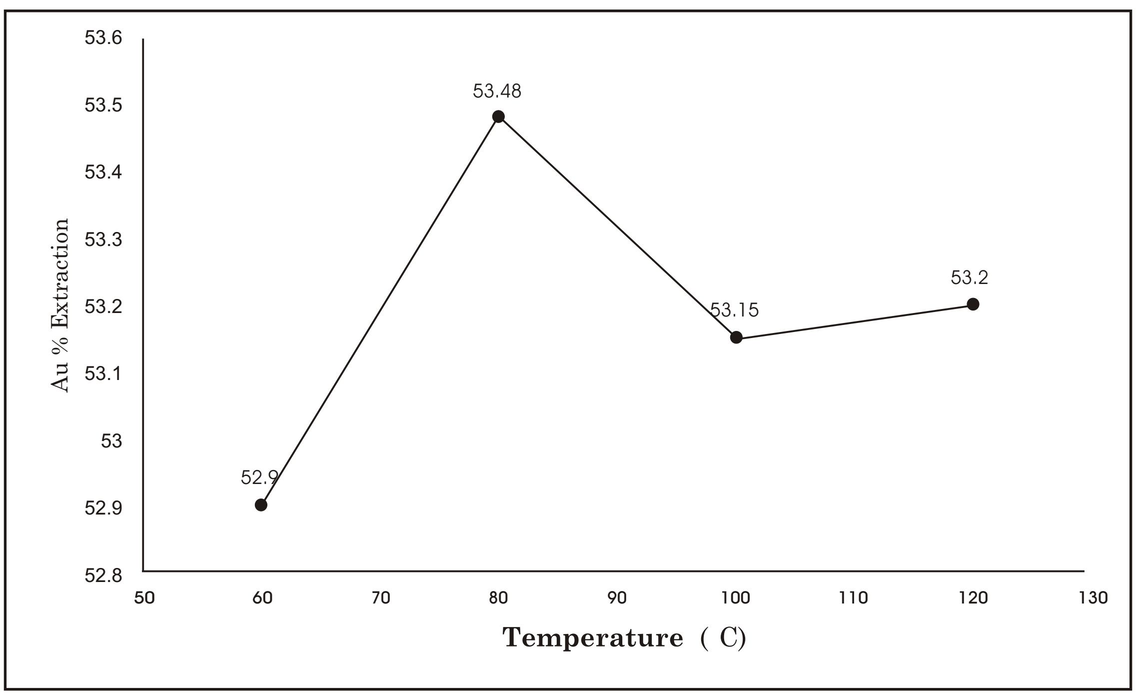


Figure 5: Effect of Temperature on % extraction of Au from Boulangerite ore showing maximum extraction at 80 °C.

3.5 Effect Of Sodium Cynaide Concentration On Extraction Of Gold:

Cyanidation tests with varying cyanide amount (in grams) were performed in order to obtain the appropriate cyanide amount. It is worth to be noted that while performing these tests the other parameters were kept constant as shown in Table 5.

From the results revealed in the Figure 6, by increasing the cyanide amount from 0.2 to 0.6 grams, the quantity of free cyanide in the pulp was increased and recovery continued its upward trend until it reached to its maximum value of 76.52. Regarding the free cyanide in pulp and acceptable recoveries, 0.6 grams of sodium cyanide was selected as the best value. Further increase in NaCN amount up to 1 gram a decrease was observed in the gold extraction. It is clear that 20 percent NaCN is required for maximum of recovery of gold from ore sample [9].

Table 5: Different parameters set for the gold extraction from boulangerite ore with varying amount of NaCN.

S. No	Ore Amount (gm)	Sodium Cyanide (gm)	Distilled water (ml)	Temp (C)	Particle Size (mesh)	Time (mins)	RPM	Au % Extraction
1	3	0.2	10	80	200	60	300	52.90
2	3	0.4	10	80	200	60	300	68.56
3	3	0.6	10	80	200	60	300	76.52
4	3	0.8	10	80	200	60	300	72.46
5	3	1.0	10	80	200	60	300	73.04

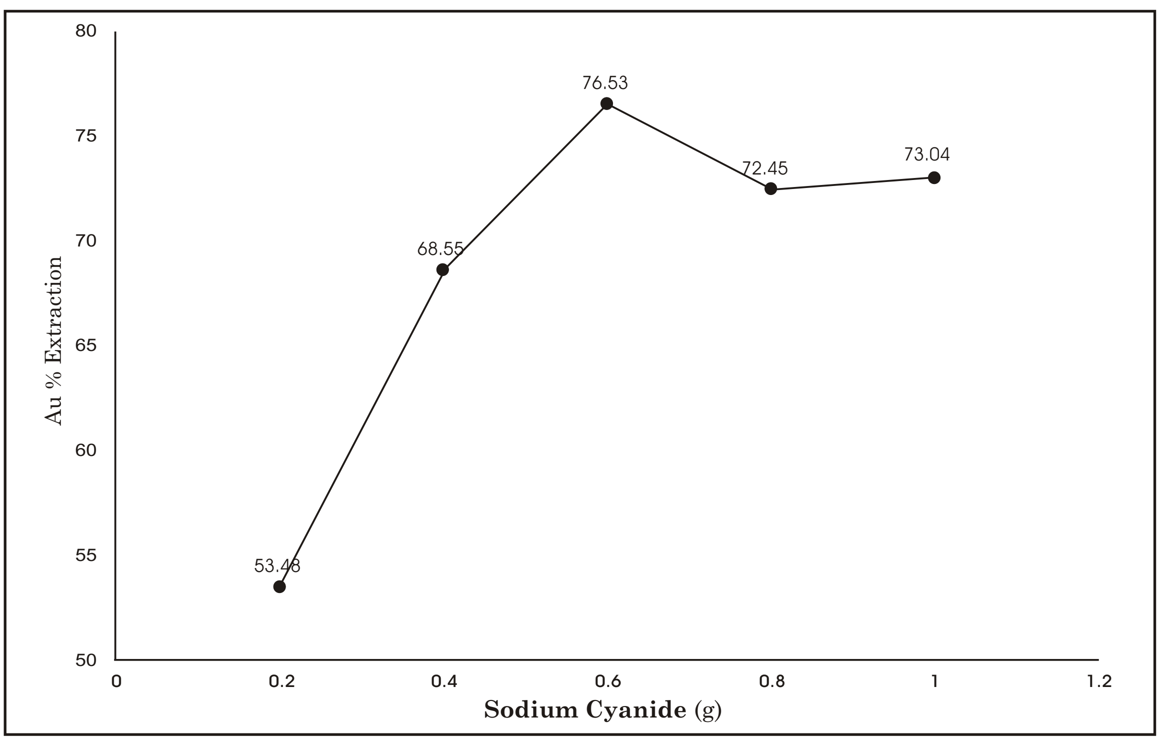


Figure 6: Effect of Sodium Cyanide amount on extraction of gold from Boulangerite ore.

4. Conclusions:

From the Energy Dispersive Spectroscopy (EDS) analysis of the ore it was verified that the main content of Boulangerite ore are Lead, Antimony and Sulfur along with traces of gold up to 13 ppm. The Scanning Electron Microscopy (SEM) shows that the ore have needle and polyhedron like morphologies oriented randomly. The polyhedron like structures has 10 to 30 um size.

Antimony in boulangerite ore was successfully minimized from 30 6 % via NaOH and Na_2S and it was treated further for the extraction of gold. For extraction of gold from boulangerite ore, different conditions i.e. leaching time, temperature and NaCN amount were studied and it was concluded that maximum extraction of gold occur at 100 minuts of leaching time, 80 °C of leaching temperature and 0.6 gram of NaCN amount. Maximum gold extraction was observed to increase from 53% to 76 % for the aforesaid conditions.

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