Recovery of Gold from Barren Black Sands in Artisanal and Small-Scale Gold Mining (ASGM)

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Abstract

Metal recovery optimisation requires that all metal-bearing components of ores and concentrates be processed until the residue contains minimal values. Gold is recovered by ASGM operations generally after gravity concentration, followed by amalgamation, heating to remove mercury and smelting. After amalgamation, the gold is processed further while the barren black sands may be discarded or stored. However, the low-tech approach offers inefficiencies in recovery, with substantial amounts of gold retained in the barren black sands. In this study, sodium cyanide (NaCN), activated carbon, and zinc shavings were used to recover gold from the barren black sands. X-ray diffraction studies showed that the black sands were predominantly made of hematite. With a head grade of 26.28 g/t, the barren black sands had average gold recovery of 96.42% after 24 hours of conventional cyanidation. The procedure accordingly recovered 25.34 g of gold from every tonne of the discarded barren black sands. Carbon-in-Leach and zinc cementation investigations showed maximum recoveries of 99.95% and 90.34% respectively. The results present important economic pathway for recovering gold from barren black sands, and serve as a platform for further research.

Keywords: Artisanal Gold Mining, Barren Black Sands, Cyanidation, Activated Carbon Recovery, Zinc Cementation

1 Introduction

Artisanal small-scale mining has grown in size and significance over the years with corresponding contributions to wealth creation employment and the national economy. It is considered one of Ghana's major livelihoods supporting activity as it employs an estimated one million people and supporting about five million more in associated service industries and markets (Mutemeri *et al.*, 2016; Marshal and Veiga, 2017). However, about 60-80% of small-scale miners operate informally and incorporate low-tech, labour-intensive mineral extraction and processing techniques (Asamoah and Osei-Kojo, 2016).

The process is targeted at ores from alluvial deposits (river sediments) or hard-rock deposits typically gold in quartz veins (Hilson *et al.*, 2014; Labonne, 2014) which is hauled for gravity concentration. The concentrate is then amalgamated using mercury and retorted to obtain the sponge gold leaving the concentrate barren (Hilson *et al.*, 2014). These ASGM techniques do not capture all of the gold and every so often, the barren concentrate from the extraction process, which is discarded as waste, contains economically viable concentrations of gold. Considering the exhaustive nature of mineral resources and undesirable environmental issues related to handling and disposing waste products from ASGM activities, this study offers a pragmatic and sustainable approach to support ASGM to recover gold from discarded barren concentrate ("Black Sands") using cyanidation, carbon-in-leach and zinc cementation techniques. This research is in support of the UN Sustainable Development Goal 9 on *Industry, Innovation and Infrastructure*.

Cyanidation is used mainly by metallurgists to dissolve gold from an ore or concentrate (Amankwah *et al.,* 2005). Mostly, due to its high stability, capacity and effectiveness in treating a wide range of ores at a relatively low cost compared with other extractants. Subsequently, the gold may be recovered after cyanidation by methods such as zinc cementation, solvent extraction, adsorption on activated carbon and aluminium precipitation (Marsden & House, 2006). Zinc cementation is the conventional/classical gold recovery method however, activated carbon adsorption technology is utilised in most of large modern gold producing mines; hence their consideration for this study.

2 Materials and Methods Used

2.1 Materials Used

Barren black sand samples weighing 3 kg was collected from cross-sections of the various ASGM sites in the western part of Ghana. The sample with particle size of 90% passing 250 microns, was homogenised and split for the various tests. The gold content in the sample was determined by fire assay. While the mineralogical composition was also determined using X-ray diffraction (XRD). Since the sampling sites utilised mercury to recover gold, the barren black sand sample was hand-panned to remove residual mercury that may be present. Panning was done using latex hand gloves. Activated carbon in addition to analytical reagent grades of lead salts, sodium hydroxide and sodium cyanide were obtained from the Minerals Laboratory of the University of Mines and Technology, Tarkwa, Ghana. Zinc shavings were acquired from one ASGM site near New Atuabo in Tarkwa, Ghana.

2.2 Method

2.2.1 Cyanidation Test

Cyanide leaching was conducted on the barren black sands to establish the selective dissolution of gold from the samples into solution. Cyanidation was conducted using 500 g of the barren black sands at 50% pulp density and 500 ppm cyanide concentration. The pH was maintained between 10.5-11.5 by the addition of sodium hydroxide. The sample was agitated for 36 hours and at intervals of 1, 2, 4, 8, 12 and 24 hours, solution samples were taken. At the end of the leaching period, the pulp was filtered, and the solutions obtained was analysed for gold by the Shimadzu AA-7000 Atomic Absorption Spectroscopy (AAS) whereas the residual solids (tailings) were assayed for residual gold by aqua regia.

2.2.2 Carbon-in-Leach (CIL) Study

For CIL study, 10 g of activated carbon was contacted with the 500 g of barren black sands, and leached at 50% pulp density and 500 ppm cyanide concentration for 36 hours. The gold in solution and solid tailings were determined using AAS and aqua regia respectively.

2.2.3 Zinc Cementation Test

The possibility for zinc shavings to precipitate gold from the pregnant leach solution obtained from cyanidation was assessed by conducting zinc cementation. Thus, 100 mL of the leach solution containing 20.81 ppm of gold was adjusted to a pH of 12 and contacted with 0.5 g of zinc shavings and 0.07 g of lead salts in an airtight container. The content was shaken at room temperature for 24 hours, after which zinc shavings holding the precipitated gold was filtered out, and the barren solution filtrate was analysed by AAS to estimate the amount of precipitated gold.

3 Results and Discussions

This study hypothesised that substantial amounts of gold can be recovered from barren black sands, and thus used cyanidation, carbon-in-leach and zinc cementation for validation.

3.1 Characterisation of Barren Black Sands

The mineralogical composition of the barren black sand samples determined by XRD presented hematite as the main mineral, whereas chemical analysis showed gold content of 26.28 g/t. The genesis of barren black sand gives the likelihood of trace quantities of mercury in the sample utilised (Styles *et al.,* 2010; Amankwah and Anim-Sackey, 2013), hence the sample was panned to eliminate residual mercury for environmental, health and safety reasons.

The panning results by physical observation showed residual mercury as depicted in Figure 1. The residual mercury weighed 0.21 g/kg showing significant mercury retention in the black sand. It is imperative that artisanal gold miners employ panning by wearing protective hand gloves to recover mercury for reuse and mitigate increasing levels of mercury intoxication in the environment. This will fulfil the UN SDG 3 on *Good Health and Well-being*.

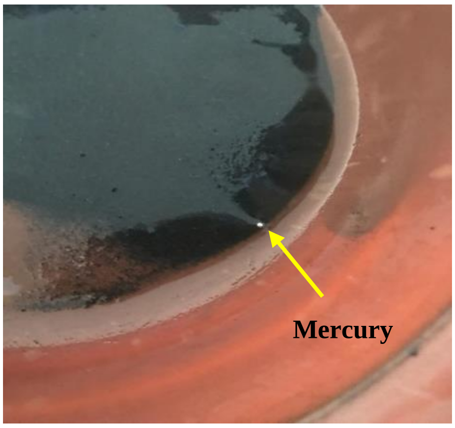

Figure 1 Panning Results showing Residual Mercury in Barren Black Sands

The ensuing sections further presents and discusses findings on the sustainable recovery of gold from the barren black sands using direct cyanidation, CIL and zinc cementation processes.

3.2 Gold in Solution after Cyanidation

The leaching kinetics curve for the sample is shown in Figure 2. Maximum gold recovery was 96.42% after 24 hours of cyanidation with the nature of the curve showing the presence of preg-borrowers in the barren black sands (Brittan, 2008).

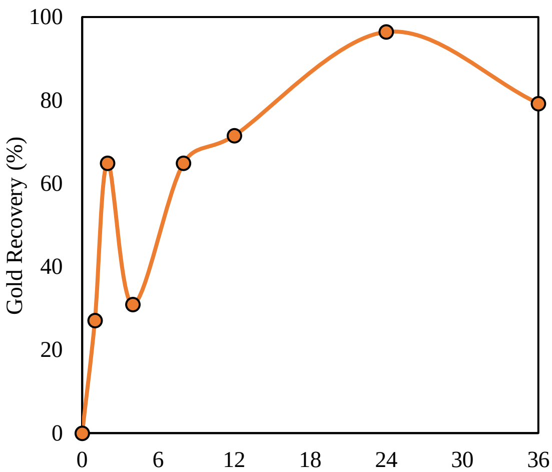

Figure 3 Gold Leaching Kinetics of the Barren Black Sands

The ability for the sample to preg-borrow the aurocyanide may be attributed to mineralogical composition.

Significant drop in recovery observed after 36 hours can be attributed to some of the following; gold concentration in solution, ionic strength, concentration of other metals, and dissolved oxygen concentration (Fleming *et al.*, 2011; Salarirad and Behnamfard, 2011; Snyders *et al.*, 2013).

3.3 Gold Recovery from Solution

3.3.1 Carbon-in-Leach

Figure 3 summarises the recovery of gold by activated carbon. The rate of gold cyanide adsorption for barren black sand was rapid after 8 hours and was controlled by the mass transport of gold cyanide species to the available activated carbon surfaces where adsorption essentially occurs (Wadnerkar *et al.*, 2015), with the highest recovery of 99.95% being achieved at 36 hours. This increase in recovery is expected as the activated carbon introduced reduced the preg-borrowing effect of the sample observed during direct cyanidation by outcompeting the natural carbons.

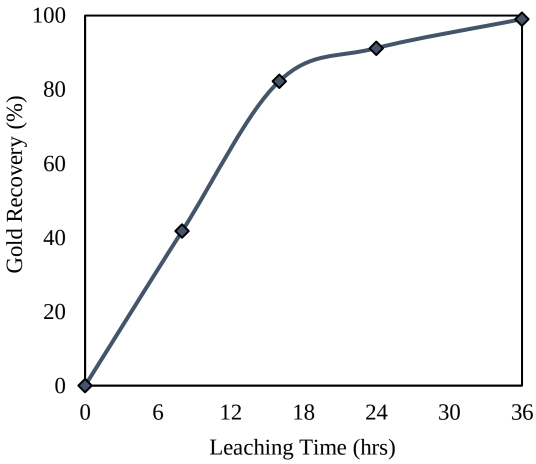

Figure 2 Activated Carbon Recovery

3.3.2 Zinc Cementation

Gold was precipitated from dilute solution of sodium cyanide over 24 hours as presented in Figure 5. The figure indicates that at the end of 24 hrs, 90.34% of the aurocyanide complex was deposited on the zinc surface leaving the barren solution with 9.72%.

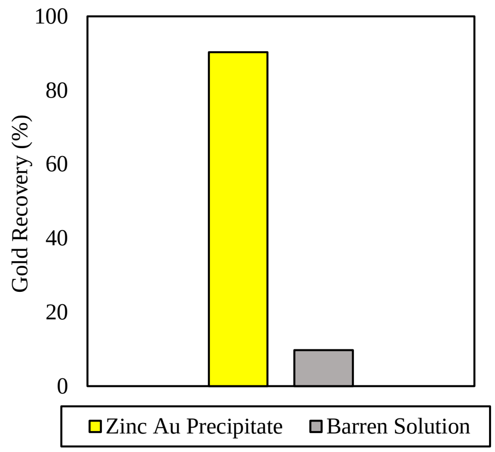

Figure 4 Zinc Cementation of Aurocyanide Solution Leached from the Barren Black Sands

The low percent recovery by the zinc can be attributed to inefficient shaking of the content, and the time interval for the shaking. This may lead to low mass transport of Au(I) cyanide from the bulk solution onto the zinc surface (Walton, 2016). Also, zinc cyanide species mass transfer to bulk solution and desorption of zinc cyanide from zinc surfaces can contribute to low percent recovery by the zinc (Marsden and House, 2006).

4 Conclusions

Barren black sands, obtained from artisanal small-scale gold mining activities, for this study was subjected to direct cyanidation, carbon-in-leach and zinc cementation. Prior to the leaching and recovery studies, the sample was panned for mercury, and the residual mercury weighed 0.21 g/kg showing significant mercury retention in the black sand. X-ray diffraction studies showed that the black sands were predominantly made of hematite. With a head grade of 26.28 g/t, the barren black sands had average gold recovery of 96.42% after 24 hours of conventional cyanidation. The procedure accordingly recovers 25.34 g of gold from every tonne of the discarded barren black sands. Carbon-in-Leach and zinc cementation investigations showed maximum recoveries of 99.95% and 90.34% respectively. This offers a pragmatic and sustainable approach to support ASGM to recover gold from discarded barren concentrate.

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