Effects of Entrained Biomass of *Phanerochaete Chrysosporium* on Carbon-In-Leach Operations

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Abstract

Carbon-In-Leach (CIL) is one of the conventional methods employed in the hydrometallurgical recovery of gold from its ores, especially where the ore contains natural carbonaceous matter that preg-robs dissolved gold. CIL is also employed in the recovery of gold from refractory ores that have undergone oxidative pretreatment. Oxidative pretreatment may be achieved using fungi, which biotransforms carbonaceous matter to reduce its ability to preg-rob gold. Such biotreated materials may be entrained with fungal-biomass, which can affect the activity of activated carbon introduced purposefully to adsorb dissolved gold. Previous works using cell-free extracts of *Phanerochaete chrysosporium* to treat activated carbon reported a decrease in its ability to adsorb gold, and a general improvement in the adsorption process when the treated carbon was washed before it was contacted with standard gold solution. This paper presents the findings of a follow-up research, in which an oxide ore was contacted with cell-free extract of *P. chrysosporium* for 24 hours to mimic fungal-treated refractory gold ore. The as-received ore and fungal-treated ore were each leached with and without activated carbon to ascertain the effect of entrained fungal biomass on oxidised gold ores, and the rippling effect on activated carbon during the CIL process. This paper reports that, at the end of the 24-h cyanidation process, the activated carbon in the as-received sample adsorbed an average of 20% more auro-cyanide than the activated carbon in the sample treated with the cell-free extract. In the absence of activated carbon, both the as-received sample and the treated sample recorded almost the same gold in solution. It can be concluded that transportation of fungal extracts into CIL operations can reduce the adsorption capacity of activated carbon, and such treated ores require proper water-washing prior to CIL.

Keywords: *Phanerochaete chrysosporium*, Carbon-In-Leach, Cell-free extracts, Auro-cyanide, Pretreatment

1 Introduction

Refractory gold ores are ores which yield low recoveries when subjected to conventional cyanidation or gravity concentration. The ores could be sulphidic, carbonaceous or double-refractory in nature (Marsden and House, 2006). Sulphidic gold ores have the mineral of interest confined in the matrices of sulphides mainly pyrite, pyrrhotite and arsenopyrite. The sulphides hinder the direct contact of the lixiviant with the mineral of interest, hence making it challenging for easy liberation and dissolution (Amankwah *et al*, 2005). Carbonaceous matter (CM) is naturally part of refractory gold ores and it comprises hydrocarbons, organic carbons (humic acid) and elemental carbons. CM in refractory carbonaceous gold ores has similar characteristics like activated carbon and adsorbs dissolved gold from its pregnant solution, a situation known as preg-robbing (Adams and Burger, 1998; Rees and Van Deventer, 2000). Due to their adverse impact on gold recovery, sulphide and CM in refractory gold ores must be completely removed, thus the ore must be pre-treated before cyanidation (Afenya, 1991). A number of pre-treatment techniques have been proven to be efficient on refractory gold ores (Adams, 2005).

Bacterial oxidation (BIOX) is a commercial pre-treatment technique which enhances gold recovery in sulphidic refractory gold ores (Thompson and MacCulloch, 2004). This process makes use of chemolithotrophic bacteria which oxidise sulphides and makes the ore amenable to cyanidation. Industrial application of BIOX has been successful because the process requires relatively lower capital cost, has lower operating temperatures and less environmental issues, employs microorganisms which are self-regenerating (Marsden and House, 2006; Ofori-Sarpong *et al.*, 2010; 2017). BIOX, though a proven technique now, faces recovery challenges in the cyanidation circuit. The process oxidises only sulphides, thus in the pre-treatment of refractory ores, CM, if present, is not treated and

continues to preg-rob aurocyanide complexes in the cyanidation gold recovery process (Amankwah *et al*, 2005; Ofori-Sarpong *et al*, 2013a; Adam *et al.*, 2017). Due to the above challenges, biological pre-treatment of CM has been researched on using various bacteria including *Pseudomonas spp., Achromobacter spp., Arthrobacter spp., Rhodococcus spp.* and *Streptomyces setonii* (Brierley and Kulpa, 1992; Amankwah *et al.*, 2005) and fungi; *Penicillium citrimum, Trametes versicolor* and *Phanerochaete chrysosporium* (Portier, 1991; Ofori-Sarpong *et al.*, 2010; Bonnah *et al.*, 2016; Konadu *et al.*, 2017). Bio-transformation of various grades of CM and sulphide materials and subsequent improvement in gold recovery have been studied (Amankwah *et al.*, 2005). Industrially, application for fungal pre-treatment is on the low, however, research works have reported that, *P. chrysosporium*, a white-rot fungus can bio-transform various grades of refractory gold ores. Ofori-Sarpong *et al*. (2010) conducted a research work which aimed at deactivating CM. After contacting lignite, bituminous and anthracite coals with the fungus, *P. chrysosporium*, gold adsorption by anthracite, which has the highest preg-robbing capacity, decreased the most (Stenebraten *et al.*, 2000; Ofori-Sarpong *et al*., 2010). The fungus through its metabolic activities creates an oxidising environment for oxidation of sulphides and passivation of active pores of CM which reduces its ability to preg-rob the aurocyanide complexes (Ofori Sarpong *et al*., 2011; 2013b; Qian Liu *et al*., 2014; Konadu *et al.*, 2017). The pre-treatment process leading to the reduction in the preg-robbing capacity of CM and the oxidation of sulphides precedes cyanidation process where activated carbon is introduced into the circuit for aurocyanide complex adsorption either by Carbon-In-Pulp (CIP) or Carbon-In-Leach (CIL) process. This is necessary to prevent or reduce the competition between CM and activated carbon for gold adsorption. Activated carbon (AC) is used to selectively concentrate dilute gold-bearing solutions to yield higher grade solutions from which gold can be extracted effectively. However, the refractory gold ore which has been bio-treated with *P. chrysosporium*, if not washed properly, could carry along entrained fungal biomass into the CIL/CIP circuit. Since AC is itself a CM in nature the biomass of *P. chrysosporium* can serve as organic foulant and reduce the activity of AC for gold adsorption (Ofori-Sarpong *et al*., 2013a; Qian et al, 2014; Bonnah *et al*., 2016; Adzigbli *et al*., 2018). A study conducted by Bonnah *et al.* (2016) to investigate the effect of fungal treatment on gold adsorption by AC using standard gold solution revealed that, entrained biomass could reduce gold adsorption on activated carbon by 18% - 21%, if the treated material is not properly washed with water. An extension of the research by Adzigbli *et al*. (2018) assessed the effect of water-washing on aurocyanide adsorption by AC in CIL following fungal pretreatment of carbonaceous ores. The authors confirmed the results by Bonnah *et al*. (2016) by reporting a decrease in the activity of activated carbon as a function of increasing contact time with the cell-free extract of *P. chrysosporium*. After washing the treated carbon with various volumes of water before gold adsorption, the activity of AC increased from 64% to 93%.

The previous papers looked at contacting AC with fungal extract prior to adsorption of gold from standard solution. The current paper mimics reality by using fungal-treated slurry in a CIL process instead of standard gold solution.

2 Materials and Methods Used

2.1 Materials

Fungal spores of *Phanerochaete chrysosporium* (bio transformer), corn bran which served as a growth media for the fungus, aluminium foil, filter papers, pH modifiers (sodium hydroxide and sulphuric acid), distilled water, activated carbon and oxide gold ore all from the Minerals Engineering Laboratory, University of Mines and Technology were the materials employed for this experimental work.

2.2 Methods Used

The experiment was carried out in the UMaT Minerals Engineering Laboratory. The procedures adopted for this work were culturing and harvesting of cell-free extract after fungal growth, pulverisation of the oxide gold ore, conditioning of pulverised gold ore with the cell-free extract at pH 4 for 24 h, washing of both treated and fresh ores as well as leaching of ores and acid digestion of residues after 24hrs. A control experiment was equally set up whereby the same volume of fresh water as used for the extract was used to contact another pulverised ore of the same mass.

2.2.1 Preparation and Culturing of Fungi

400 g of corn bran was weighed and introduced each into two clean PYREX Narrow Mouth Erlenmeyer Flasks. 120 ml of distilled water was added and the flasks were covered with aluminium foil and placed in an MRC Steam Sterilizer Autoclave at 121 ºC for some time to get rid of residual microorganisms. Upon cooling, the media were inoculated with fungal spores suspended in 5 ml of distilled water. The culture was placed and allowed to grow at a temperature of 35 ºC for 10 days in an MRC Orbital Shaker Incubator. Holes

were punched on the aluminium foil by way of introducing oxygen into the culture. Fungal growth was assessed to be efficient after the incubation

period as shown in Figure 1.

Figure 1 A 10-Day Culture of *P. chrysosporium*

2.2.2 Harvesting of Cell-Free Extract after Fungal Growth

After the 10 days' growth period, the culture was removed from the incubator and pulped with 5 L of distilled water. The pulp was filtered using a cheesecloth to separate the fungal biomass, that is, the cell-free extracts of *P. chrysosporium* from the growth media as seen in Figure 2. The residues were sterilised and disposed. The pH of the cell-free extract was checked and recorded as 6.25.

Figure 2 Cell-Free Extract After Culturing

2.2.3 Pulverisation of the Oxide Gold Ore

8 kg of oxide gold ore was crushed and milled to 80% passing 106 µm screen. The ore was crushed using the Jaw, Cone and Roll crushers respectively in achieving 100% passing the 1 mm screen. The ore was further pulverised using a ball Mill to achieve the set target.

2.2.4 Conditioning of the Pulverized Ore with Cell-Free Extract at pH 4 for 24 h

Two clean bottles were sterilised and 1 kg each of the pulverised ore was weighed into a bottle and pulped with the cell-free extract at a density of 30%. Each slurry was conditioned at a pH of 4 using sulphuric acid. The same volume of fresh water was used to pulp the control experiment to 30% pulp density. The set-up was allowed to sit for 24 h.

2.2.5 Washing of Both Treated and Untreated (Control) Ores with Water

After the 24 h, both the treated and the untreated (control experiment) set-ups were washed thoroughly using 20 L of water conditioned at pH 11 for each set-up.

2.2.6 Leaching

The washed pulverised ores were again pulped at 50% density and poured into bottles. The pH of the slurries ranged between 8.20-8.39. The slurries were conditioned to pH 11 by the addition of sodium hydroxide (NaOH) and a cyanide strength of 300 ppm. Activated carbon, weighing 12 g each, was introduced into 2 of the bottles, one of which contained a treated and the other an untreated ore. The bottles were set to undergo a 24-h cyanidation process via the bottle roll test, and with solution samples taken at 1, 2, 4, 8, 16 and 24 h. After 24 h, the tailings materials were washed, dried and 50 g from each sample weighed for acid digestion. All solution samples were analysed to determine the gold in solution and the adsorption ability of the activated carbon, using the Varian AA240FS Atomic Absorption Spectrometer (AAS).

2.2.7 Acid Digestion of Solid Residue

To determine the tailings value, 50 g of the residue from each bottle was weighed into a Pyrex beaker. Aqua regia was prepared in the ratio of 3:1 respectively with 75 ml of HCL and 25 ml of HNO_3 added to the residue in each beaker. The set-ups were heated on an electric burner for 10 minutes to speed up the reaction. The mixtures were filtered and 10 ml each of the filtrates were diluted to 50 ml and analysed using the Atomic Absorption Spectrometer.

2.3 Analysis of Data

The head grade, which is the total gold in the ore was determined. The recoveries and the carbon adsorption at the various periods were also calculated as shown in Equations 1 and 2;

$$\text{Gold recovery (\%)} = \frac{\text{Gold in solution}}{\text{total gold in ore}} \times 100\% \qquad (1)$$

$$\% \text{ adsorption} = \frac{\text{Gold adsorbed}}{\text{total gold in ore}} \times 100\% \quad (2)$$

3 Results and Discussion

This paper sought to investigate the effect of entrained biomass of *P. Chrysosporium* on aurocyanide adsorption by activated carbon. The effect was analysed by contacting the cell-free extract of the fungus with the fresh pulverised ore. For the purpose of this work, four (4) different experiments were carried out, and fungal-treated and as received gold ores were subjected to cyanidation test work with and without activated carbon. The samples were set to undergo a 24-h cyanidation process via the bottle roll test, with solution samples taken at 1, 2, 4, 8, 16 and 24 h. The as-received gold ore was set as a controlled experiment. The following sections present and discuss the results obtained.

3.1 Gold in Solution during Leaching with Activated Carbon for the Treated and As-Received Gold Ore

Cell-free extract of the fungus was treated with pulverised gold ore sample and the set-up was allowed for 24 h. A control experiment was also set up by pulping the as-received sample with the volume of fresh water being the same as that of the cell-free extract and allowed for same duration. The two samples with pulp densities of 50%, were leached in the presence of activated carbon at pH 11 for 1, 2, 4, 8, 16, and 24 h. The amount of gold in solution expressed as percentages at the various leaching periods are presented in Figure 3.

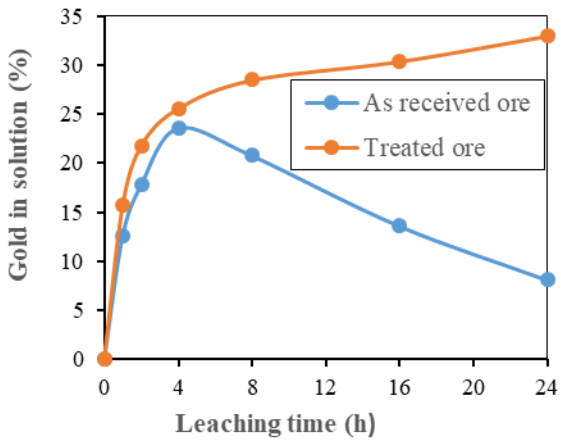

Figure 3 Gold in Solution as a Function of Leaching Time with Activated Carbon

Figure 3 shows the amount of gold that was recovered in solution in the as-received and the treated samples for the various leaching periods. The gold in solution obtained for the as-received samples were relatively low. This was as a result of the presence of the activated carbon in the slurry. The activated carbon adsorption in the early periods of cyanidation was low so a relatively high amount of gold was in solution. After 4 h, the gold in solution started decreasing for the rest of the leaching periods and this can be related to the fact that most of the aurocyanide had been adsorbed by the activated carbon. The treated ore on the other hand saw relatively much gold in solution for the various hours. The activated carbon could not do more adsorption and the gold in solution kept increasing throughout the leaching process. This decrease in aurocyanide adsorption can be attributed to the fact that the cell-free extract present in the slurry modified the surface of the activated carbon and reduced its adsorption capacity by increasing the surface oxygen functional groups, destroying the graphitic structure, and decreasing the surface area (Amankwah and Yen, 2005; Ofori-Sarpong *et al.*, 2010; 2013b). It can therefore be said that, at the end of the 24 h leaching process, the activated carbon in the as-received sample adsorbed relatively more aurocyanide than the activated carbon in the sample treated with the cell-free extract.

3.2 Gold in Solution during Leaching without Activated Carbon for the Treated and As-Received Gold Ore

This result was obtained after conditioning the gold ore with the cell-free extract of the fungus and setting up a control experiment (untreated ore) which were then leached, maintaining all conditions applied in the previous experiment but in the absence of activated carbon. This work was done to ascertain the extent to which the gold ore in each scenario would respond to cyanidation. The amount of gold in solution expressed as percentages at the various leaching periods are presented in Figure 4. It was observed that the gold in solution for both the as-received and the treated ores were relatively high and increased with time. This was attributed to the absence of activated carbon in the slurries.

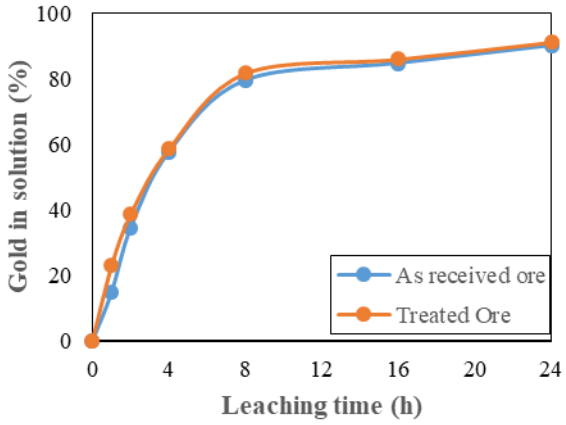

Figure 4 Gold in Solution as a Function of Leaching Time without Activated Carbon

3.3 Gold Adsorption by Activated Carbon as a Function of Time for both As-Received and Treated Gold Ores

After the Carbon-In-Leach test work for the as-received and treated gold ores, the quantity of gold that was adsorbed by the activated carbon at the varying periods (4, 8 and 24h) were determined and presented in Figure 5

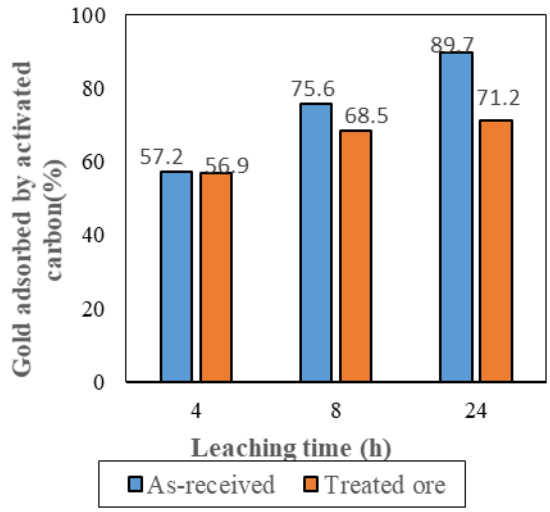

Figure 5 Percentages of Gold Adsorbed with respect to Leaching Time for the Two Scenarios.

The decrease in the adsorption capacity of the activated carbon in the fungus treated sample can be attributed to the fact that the carbon might have been potentially fouled by the entrained biomass present in the treated ore sample (Bonah *et al.*, 2016). It is suspected that the entrained biomass on the pre-treated ore passivates the surface of the activated carbon thereby reducing its adsorption capacity. It can therefore be said that, at the end of the 24 h adsorption process, treated gold ore containing activated carbon recorded a relatively lower adsorption as compared with the as-received.

3.4 Overall Gold Recovery in Solution and by Activated Carbon at the end of the CIL process.

This result was obtained by considering the gold recovered in solution and by the activated carbon at the end of the 24 h Carbon-In-Leach process of both the as-received and treated ores. The overall amount of gold in solution and on activated carbon expressed as percentages with respect to their various leaching times are presented in Figure 6. Again, it was observed that the overall gold recovered in the treated ore was relatively low as compared to the as-received ore. This could probably be as a result of the entrained biomass reducing the rate of gold dissolution by coating the surface of the ore hence inhibiting the action of the lixiviant on the ore and causing it to report in the solid residue (tailings) instead.

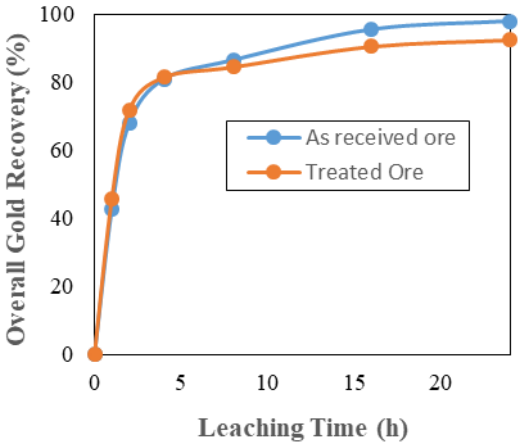

Figure 6 Overall Gold in Solution and on Activated Carbon after CIL as a Function of Leaching Time.

4 Conclusions and Recommendation

This research work investigated the effects of entrained biomass of *Phanerochaete chrysosporium* on Carbon-In-Leach operations. Activated carbon was used for aurocyanide adsorption at different times and from the results obtained, it can be concluded that the entrained biomass had destructive effect on carbon by increasing the surface oxygen functional groups,

destroying the graphitic structure and passivating its active sites leading to a decrease in surface area. This reduced the adsorption capacity of the activated carbon as well as its activity. From adsorption capacity of 89.7% using the untreated (control) gold ore leaching with carbon, fungal-treatment decreased the gold adsorption capacity of activated carbon to 71.2%.

It is therefore recommended that, oxidised feed from pre-treatment section prior to CIL should be washed thoroughly.

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