

Effects of Potassium Nitrate (Saltpetre) On Gold Cyanidation*

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Abstract

Experimental work and analysis have been carried out in this investigation to ascertain the effect of saltpetre in the Ghanaian market on gold dissolution rate and recovery. The locally produced saltpetre has been used in this study as a potential oxidising agent and its performance compared with already existing oxidising agents (hydrogen peroxide and air) in gold cyanidation process. The cyanidation test was conducted on a free milling, oxide gold ore. The outcome of the leaching test showed that saltpetre could be used as an oxidant for gold cyanidation. After using saltpetre as an oxidant in cyanide leaching, Au recovery of approximately 99% was realised while approximately 98% recovery was obtained from cyanide leaching involving hydrogen peroxide and atmospheric air as oxidants. Hydrogen peroxide (H₂O₂) however, proved to be a better oxidant than saltpetre in terms of leaching kinetics. The slow leaching kinetics for the saltpetre when compared to H₂O₂ is attributed to the probably low purity of saltpetre. Saltpetre also proved to be a better pH modifier in terms of alkalinity, compared to the normally used lime in the gold industry. The pH modifying ability of saltpetre despite its natural pH of about 7 is attributed to its dissociation in water to produce potassium hydroxide (KOH), a good pH modifier.

Keywords: Saltpetre, Potassium Nitrate, Hydrogen Peroxide, Leaching, Gold Cyanidation

1 Introduction

Oxidising environment is generally required in gold cyanidation process to effect gold dissolution. The role of oxygen in cyanide leaching is extensively explained in literature; (Arslan *et al.*, 2003; Marsden and House, 2006). Oxygen is known to increase the gold dissolution rate in gold cyanidation process (Guzman *et al.*, 1999; Kondos *et al.*, 1995; Kondos *et al.*, 1996). The current major challenge of using air as an oxidant in gold cyanidation is that diffusion of oxygen across the pulp boundary layer is very slow and this reduces the overall kinetics of the process (Pinnel, 1979). Experimental work carried out by Kydryk and Kellog (1954) sought to use H₂O₂ as an oxygen supplier other than air as an oxidant owing to the fact that one of the most important conditions for fast dissolution of gold is the presence of readily dissolved oxygen in the pulp. Although H₂O₂ has been successful in enhancing leaching kinetics in gold cyanidation, it has proven to be an expensive reagent. Currently, investigations are focused on the use of an alternative and cheaper oxidising agents to enhance gold leaching recoveries. Leaching is mostly applied to gold particles that are too fine to be recovered by gravity methods. The dissolved metal should be stable in the aqueous phase and therefore metals that are not stable in the aqueous phase require a complexant to ensure stability. Cyanidation is a leaching process that requires the use of cyanide as a complexant in order to ensure that gold ions remain stable in the water solubility region (Ling and Korey, 1996). Gold, being a noble metal, is not easily affected by water and acids. It requires a very strong oxidising agent to move from the stable state to its ionic states (Au⁺ and Au³⁺) (Krauskopf, 1951). Strong

oxidising agents have been tested and proven feasible (Arslan *et al.*, 2003; Esmkhani *et al.*, 2013; Knoore *et al.*, 1993) while others are under investigation. Hydrogen peroxide is known to the mining industry as a powerful oxidant (Knoore and Griffiths, 1984). The cyanidation and oxidation are of prime importance in the conversion of gold to water soluble cyanides. It is established that insufficient transfer of oxygen from gaseous phase into ore pulp is often the cause for low levels of dissolved oxygen and correspondingly slow extraction kinetics and low gold recoveries (Loroesh, 1990). Although very efficient as compared to normal atmospheric air, concerns have been raised regarding high price of hydrogen peroxide and lime consumption. This has led to research in alternative oxidising agents that can oxidise gold effectively and economically. One of the most important nitrate salts commercially used is potassium nitrate. It occurs naturally as thin white granular crusts or masses or in minute needle-form crystals, and as a thin coating on earth, walls and rocks. It is a transparent crystalline salt with a cooling, rather sharp, saline taste. It has a very high solubility between 0.32x10⁶ to 0.18x10⁶ g/m³ in water depending on its purity. It is a powerful oxidant in the explosives industry. The high oxidising ability and solubility of potassium nitrate could be advantageous in gold cyanidation hence its potential to be used in the mining industry. In this investigation however, reagent grade potassium nitrate is not used but rather, saltpetre, acquired from the Ghanaian market has been used to ascertain its effectiveness in gold cyanidation once it is known to be majorly made up of potassium nitrate (MGRG, 2006).

2 Resources and Methods Used

About 5 kg free milling, oxide gold ore was used for this investigation. Sodium cyanide (NaCN) and lime (CaO) were obtained from the minerals engineering laboratory of the University of Mines and Technology, Tarkwa-Ghana. These were respectively used as complexant and pH modifier during leaching studies. The potassium nitrate (saltpetre) used in this investigation was obtained from the local producers. It is normally produced from raw materials such as the shells of *Parkia biglobosa* (dawadawa), corncob and dry maize stalk. Hydrogen peroxide was obtained from the minerals engineering department of the University of Mines and Technology. Laboratory size Jaw, cone and roll crushers were used for size reduction of the ore. A laboratory size ball mill was also used in grinding the samples to the required size for the various test works in this study.

2.1 Sample Preparation

The gold ore sample as received contained about 2.5% moisture hence was dried in the laboratory oven. A dry sample was thus used for this investigation. Sample contamination was avoided by thoroughly blowing off any residual samples on the laboratory equipment. The Jones' riffle sampler was used to divide the bulk sample into sub-samples of 1 kg. Grindability test was then conducted on the ore to determine the time required to grind 1 kg of material to 80% passing 106 μm . Grindability test established the time required to grind 1 kg of material to 80% passing 106 μm to be 8 min. The particle size obtained from grinding was used for this investigation as the sample is already being processed by a mining company in Ghana and is producing higher recoveries. 500 g was sampled from each ground sample for the major test works.

2.2 Leaching Test

Leaching tests were conducted on the 0.5 kg sampled ores. All leaching tests were conducted at 50% pulp density, 250 ppm cyanide concentration and 10.5-11 pH range. Acid digestion (aqua-regia) was performed on the resulting tailings to estimate the residual gold. Three two (2) litre capacity bottles were obtained and used for the bottle roll leaching tests. The leaching bottles were labelled A, B and C. The labels A, B and C respectively represent the leaching test works done using atmospheric air, saltpetre and hydrogen peroxide as oxidising agents. The sampled 0.5 kg of the ground samples were transferred into each of the three bottles and pulped at 50% density. 333.3 ml of tap water was used in the case of C due to the additional use of hydrogen peroxide in that test.

166.7 ml of hydrogen peroxide was thus transferred into leach bottle C to make up for the 50% pulp density and to attain a concentration of 2% hydrogen peroxide in the leach bottle. The bottles with the various contents were placed on rollers for 5 min to ensure a uniform mixture of the pulp. The natural pH of the pulp was measured using a TPS pH meter and was recorded to be in the range of 9 and 9.1 for the three samples. Also, 10 g of saltpetre and 2% strength of hydrogen peroxide were dosed in leach bottles B and C, respectively. Bottles B and C were allowed to roll for a further 5 min to ascertain the effect of saltpetre and hydrogen peroxide on pH. The pH values were thus recorded to be 10.71 and 8.41 respectively. The recorded pH values of bottle A and C were modified to between 10.5 and 11 with the addition of lime. No lime was used in test B once the pH recorded after saltpetre addition already fell in the desired pH range. Each bottle was then placed on the rollers as shown in Fig. 1 and leached for 24 hours. This residence time was chosen since it is currently the residence time used in leaching ores of the mine from which the ore was obtained.

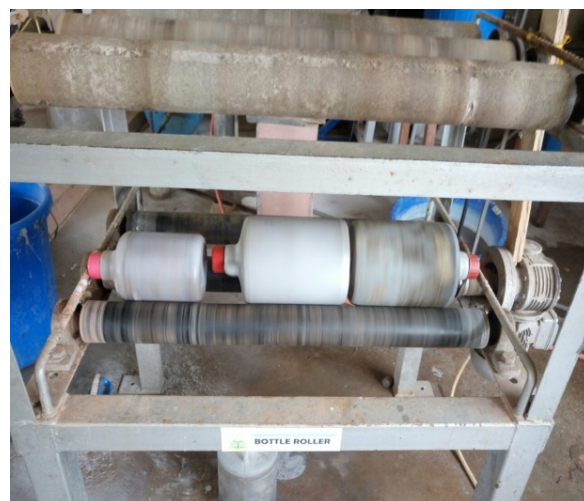


Fig. 1 Leaching of Various Gold Ore Samples

Whilst leaching, samples were taken at designated time intervals of 2, 4, 8, 12, 16 and 24 h to monitor the performance of each oxidising agent in the leaching of the mineral of interest. About 50 ml of solution samples was obtained from each test. The various solution samples were then analysed for gold concentrations using a VARIAN AA240FS Atomic Absorption Spectrometer (AAS). The pH of samples A and C dropped below 10.5 hence the pH of samples A and C was raised to above 10.5 using lime after solution samples were taken. The drop in pH could be attributed to other process factors that usually govern the actual pH conditions applied, such as the dissolution rate of other ore constituents (copper, iron, tellurium, antimony, and arsenic minerals), which can negatively affect gold

leaching and pH modification and precipitation of solution species (Ramli and Osman, 2015). The pH of sample B however, did not drop below 10.5 hence no lime was used in sample B during the entire leaching process. Cyanide concentration at the 4th hour was topped up from 180 ppm to 250 ppm. This was to ensure that there was enough free cyanide to complex the dissolved gold.

2.3 Acid Digestion of Tailings

After the 24th hour sampling, the tailings of each sample was washed thoroughly with tap water to get rid of residual cyanide and gold. The washed samples were transferred into clean pans and dried in an oven at 105 °C. Aqua regia (1:3 portions of HNO₃ and HCl, respectively) test was performed on 50 g of each of the tailings sample on a hot plate for 10 minutes. Filtrates of the digested samples (A, B and C) were analysed using the AAS for gold concentrations. Fig. 2 summarises the major works carried out in this investigation.

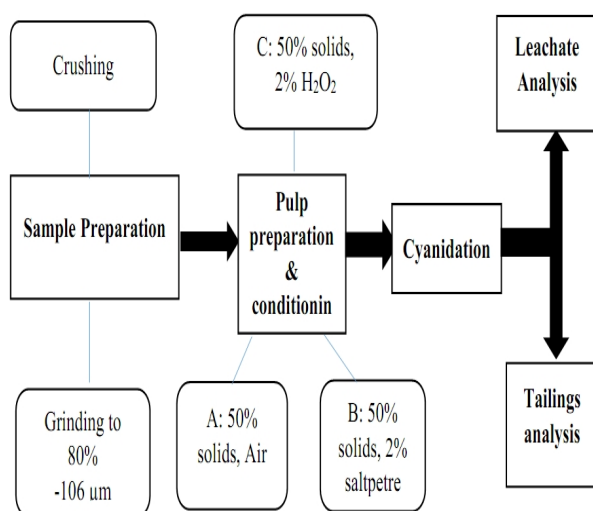


Fig. 2 Summary of Experimental Work

3 Results and Discussion

3.1 Effect of Saltpetre (Potassium Nitrate) on Leaching

Fig. 3 shows gold recovery as a function of time for the various oxidising agents. The results show a general trend of an increase in gold recovery with time for all oxidising agents. The results also show that the use of any of the oxidising agents after 24 hours leaching time results in approximately the same gold recovery. The maximum recovery of gold after 24 hours were calculated to be 98.61%, 98.55% and 97.64%, respectively, for the saltpetre, H₂O₂ and atmospheric air. The ability to recover about 98% of gold when saltpetre is used suggests that saltpetre can be used as an alternative

oxidising agent during gold cyanidation process. The very high amount of the gold dissolving in solution with respect to the total gold confirms that the ore used in the investigation is a free milling ore.

Kinetics study for the various oxidising agents was also indicated (Fig.3) to ascertain the effectiveness or performance of saltpetre in relation to H₂O₂ and air purging systems. It was shown that the rate of gold dissolution using H₂O₂ as oxidising agent is faster compared to when saltpetre or atmospheric air is used. Fig. 3 shows that at about 16 hours of leaching, 97% of gold recovery was recorded for H₂O₂ whereas 90% and 72%, respectively, were recorded for the saltpetre and air. The gold dissolution rate for the saltpetre ranged between that of H₂O₂ and atmospheric air. The high rate of dissolution of gold in the case of H₂O₂ is as a result of the availability of readily dissolved oxygen for gold dissolution. The efficiency of saltpetre as an oxidising agent is directly related to the rate at which saltpetre dissolved in solution. The faster its dissolution rate, the greater the oxidising ability. In other words it is asserted that the locally acquired saltpetre was not made up of 100% KNO₃ (MGRG, 2006) hence rendering the saltpetre with a degree of impurity. The reagent hence was sparingly soluble. Additionally, because the saltpetre was introduced as a solid, as compared to hydrogen peroxide and atmospheric air, it will take some time to dissolve in solution. This accounts for the relatively slow kinetics of potassium nitrate (saltpetre).

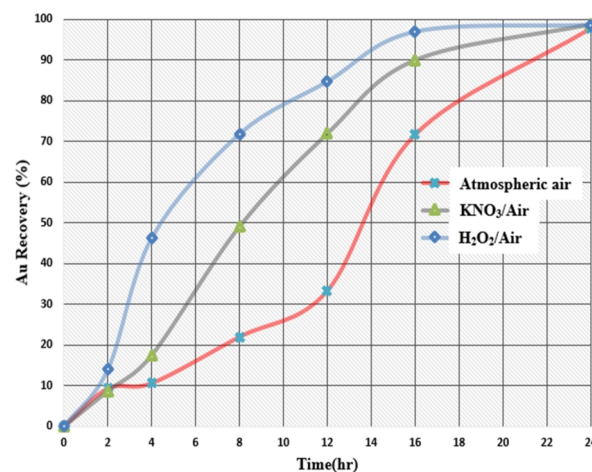


Fig. 3 Au Recovery as a Function of Time for Various Oxidants

3.2 Effect of Potassium Nitrate on Lime Consumption and pH

Fig. 4 shows that saltpetre has a significant effect on pH and lime consumption. Saltpetre proved to be a pH modifier as it provided the needed pH

range during the entire leaching process. The pH of saltpetre is naturally neutral but when dissolved in water results in the formation of KOH (equation 1). The KOH is thought of to be the reagent causing the increase in pH from 9.01 to above 10.5 at the initial stage.



The pH dropped slightly at the end of the 24 hours to 10.68, requiring no lime addition. As compared to lime as a typical pH modifier, saltpetre proved to be a good and stable pH modifier. This emanates from the fact that the pH modified with lime dropped significantly, which was not the case in using saltpetre as pH modifier. Without saltpetre addition, the amount of lime consumed at the end of the entire 24 hours of leaching was 0.8 g/L. The use of H_2O_2 further increased the lime consumption to 1.1 g/L which clearly confirms that saltpetre has the advantage of being used as an oxidising agent as well as a pH modifier. Fig. 4 shows the associated lime consumption using each of the oxidising agents.

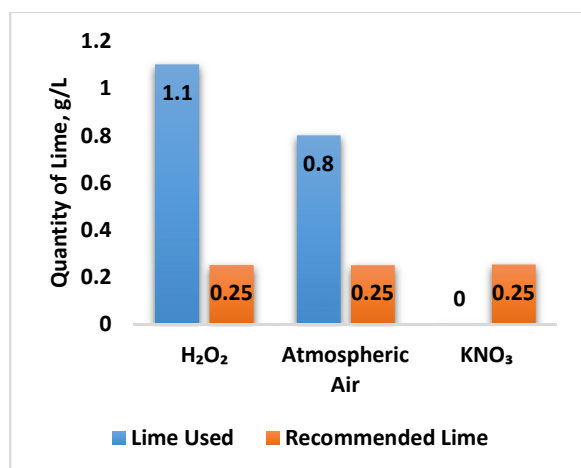


Fig. 4 Total Lime Consumption during Leaching

4 Conclusions

The performance of saltpetre (KNO_3) in gold cyanidation as against air and hydrogen peroxide as oxidants was investigated. It was comprehended from the investigation that the use of saltpetre can be used as an alternative oxidant. Comparatively, H_2O_2 proved to be better than saltpetre in terms of the leaching kinetics. From the results, potassium nitrate will be a potential replacement of hydrogen peroxide if residence time is relatively longer. Hydrogen peroxide will certainly be of preference for shorter leaching times. Notwithstanding this, it is clear that the slow kinetics of leaching when using saltpetre does not pose any challenge to the overall recovery of gold at the end of leaching. It is envisaged that a purer form of potassium nitrate or

saltpetre would overcome the slow kinetics challenge during gold dissolution which can potentially result in the cut down of residence time during gold cyanidation. The results also show that apart from the oxidising potential of saltpetre, it could be used as a pH modifier during gold cyanidation. The pH modifying ability of saltpetre results in no lime usage in gold cyanidation which would potentially offset the huge cost of lime in gold processing plants where lime is used as pH modifier.

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