Characterization of Acid Producing Potential of Spent Ore from Heap Leach Plant

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Abstract

Heap leach method is a method to process ore in a gold mine where the ore is heaped on open-air impermeable lined leach pads and irrigated with alkaline cyanide solution that percolates through the heap and leaches the gold. There are two types of heap, namely permanent or static and on-off or dynamic heap. In the static heap, the new heap cycle gold ore are placed on top of the older heap to form multiple stacking. Whereas at the end of heap cycle the spent ore in the dynamic heap will be removed from the pads and disposed in the waste dump.

Hydrothermal, in particular high sulfidation epithermal, gold ore deposit has generally been strongly overprinted by surface weathering (oxidation) mechanisms near-surface. This type of deposit is characterized by the abundance of sulfide minerals especially in the transition and fresh zones which lead to the forming of acid mine/rock drainage (AMD) both from waste rock and ore. As one of the important environmental issues in the mining operation AMD potential should be managed properly and it requires the good understanding the geochemical characterization of waste rock.

In a static heap leach operation it is also important to understand the geochemical characteristics of spent ore because it should be dumped in the waste dump after cyanide irrigation process. The results show that there is only very slight change in geochemical characterization of PAF ore after being irrigated with cyanide solutions. This finding is important in the development of AMD management measures in waste rock and spent ore dumps. Potentially acid forming spent ore should be encapsulated to prevent the formation of AMD while non-acid forming spent ore could be used as capping material in the PAF encapsulation system.

Key words: Spent ore, heap leach, acid mine drainage

Introduction

In the last 15 years several new gold mines have been developed in various part of Indonesian archipelago extracting hydrothermal type of gold deposit. Hydrothermal deposits are formed by the concentration of some elements as the product of reaction between ore-bearing hydrothermal fluid and wall-rocks. This ore systems can be found in various geological settings and are hosted in different type of wall-rocks (Zhu et al, 2011). Epithermal deposit is hydrothermal deposit formed at shallow depth and can be distinguished into two principle styles of mineralization, namely low and high sulfidation (White & Hedenquist, 1995). The shallow epithermal environment in mining areas is dominated by intensely hydrothermally altered (silica-clay-alunite-pyrite) volcanoclastic and intrusive rocks. This broader intermediate argillic alteration envelope in some areas is cross-cut by localized structures that facilitated advanced argillic alteration. Advanced argillic alteration is characterized by extreme acid leaching of the volcanic host-rock and the resulting removal of mobile cations to leave only the most acid-resistant elements in the form of stable secondary minerals (vuggy silica, silica-alunite, silica-alunite-clay, silica-clay-alunite and silica-clay). This study is related to the high sulfidation epithermal gold deposits in Indonesia that are characterized by the abundance of sulfide minerals, therefore, acid mine/rock drainage (AMD) becomes one of the important environmental issues in the mining operation as geochemical characterization has indicated the potential of AMD generation both in the ore and waste rock.

In some mines, heap leach method has been implemented to process the ore and produce dore bullion for further refining process. Heap leaching is a technique where run-of-mine or crushed and/or agglomerated gold ores are stacked over an engineered impermeable pad, irrigated with alkaline cyanide solution that percolated through the heap under atmospheric conditions. The leachates or metal loaded solutions are collected for metal recovery processes. This method is selected primarily to take advantage of its low capital cost relative to other methods although the recovery is generally lower than agitated leach plant. There are two common types of pads used in gold heap leaching, namely permanent heap construction on a pad with multiple stacking and on-off pads or single stacking (US EPA, 1994). Permanent heaps are typically built in lift where the leached ore is not removed and the new ore will be stacked on top of it. This method is sometimes defined as static heap leach. In single stacking method the spent ore will be removed from the pad and new fresh ore will be placed on the pad. This method is sometimes referred as dynamic heap method.

In the dynamic heap method, spent ore is usually placed in the waste dump. Since some of the ore is classified as potentially acid forming material, it is important to understand whether the spent ore has the potential to generate AMD, in particular when the ore before leaching is classified as potentially acid forming. Accordingly, a proper management method could be developed to mitigate the AMD problem.

Samples and Methods

The samples were taken from the dump of single stacking or dynamic heap leach spent ore after being irrigated with cyanide solution for more than 60 days. For comparison, spent ore samples were also taken from a multi-stacking heap leach which is already in operation for almost 10 years. Respective ore samples were collected from both mine sites.

All rock samples underwent static test comprising total sulfur, acid neutralization capacity (ANC), paste pH and net acid generation (NAG) tests. Column leach kinetic tests were also conducted to all samples for weeks.

Static testing allows for the direct comparison of the amounts of acidity, expressed in maximum potential of acidity (MPA) assuming it is the function of total sulfur only, and acid neutralization capacity (ANC) present in each sample. The positive value of net acid producing potential (NAPP) indicates that the sample has an excess of acid-generating minerals and classified as potentially acid forming (PAF).Conversely, excess neutralization potential is expressed by a negative value of NAPP and this sample is deemed non-acid forming (NAF). For acid generation test, the sample is mixed with a strongly oxidizing solution which is intended to rapidly dissolve all acid-forming phases. If sufficient neutralization capacity is present the NAGpH will exceed a value of 4.5 in the final solution and the sample is classified as NAF. PAF sample is defined if the produced acid outweighs the neutralization capacity indicated by NAGpH value of less than 4.5.

While static testing could not determine the kinetics of AMD generation process, kinetic testing, in this case column leach test, will give the timing of AMD onset and could be used to predict the mine drainage water quality as well.

Results & Discussion

a. Dynamic heap leach (DHL) spent ore

The results of static test for spent ore samples representing a dynamic heap leach is shown in Table 1. According to standard screening criteria both for acid-base accounting and net acid generation test the samples are classified as PAF and DHL spent ore 1 sample shows more acid potential than DHL spent ore 2.

Table 1 *Static Test Results of DHL Spent Ore Samples*

Sample Code	TS [%]	MPA*)	ANC*)	NAPP*)	NAG pH	NAG pH = 4.5*)	NAG pH = 7*)
DHL spent ore 1	2,26	69,00	0,0	69,20	2,49	50,30	57,20
DHL spent ore 2	0,45	13,78	0,0	13,78	2,94	6,70	8,30

Remarks: *) = in kg H_2SO_4/ton of rock; TS = Total Sulfur [%], MPA = Maximum Potential of Acidity, ANC = Acid Neutralizing Capacity, NAPP = Net Acid Producing Potential, NAG = Net Acid Generation

***Table 2** Static Test Results of DHL Ore Samples (Praseto, 2015)*

Sample Code	TS [%]	MPA*)	ANC*)	NAPP*)	NAG pH	NAG pH = 4.5*)	NAG pH = 7*)
DHL ore 1	2,05	62,80	0,00	62,80	2,44	26,90	30,00
DHL ore 2	0,42	12,90	0,00	12,90	2,82	9,40	10,40

Remarks: *) = in kg H_2SO_4/ton of rock; TS = Total Sulfur [%], MPA = Maximum Potential of Acidity, ANC = Acid Neutralizing Capacity, NAPP = Net Acid Producing Potential, NAG = Net Acid Generation

The high-sulfidation mineralization has been strongly overprinted by surface weathering (oxidation) mechanisms near-surface. This weathering process has produced enrichment in gold and silver and depletion in copper and sulfides resulting in an ore type that is highly amenable to the heap leaching. However, economic-grade Au mineralization may still exist at depths that are only partly oxidized or unoxidized. Naturally, these transition and fresh zones contain higher abundances of sulfide minerals (predominantly pyrite). Typical characteristics of ore samples, predominantly oxidized ore, in AMD generation is shown in Table 2. Both ore samples are classified as PAF although from the NAPP value DHL ore 2 sample is less acid potential. However, column leach test results for both ore samples are quite similar with pH range between 2 and 4 (see fig. 1).

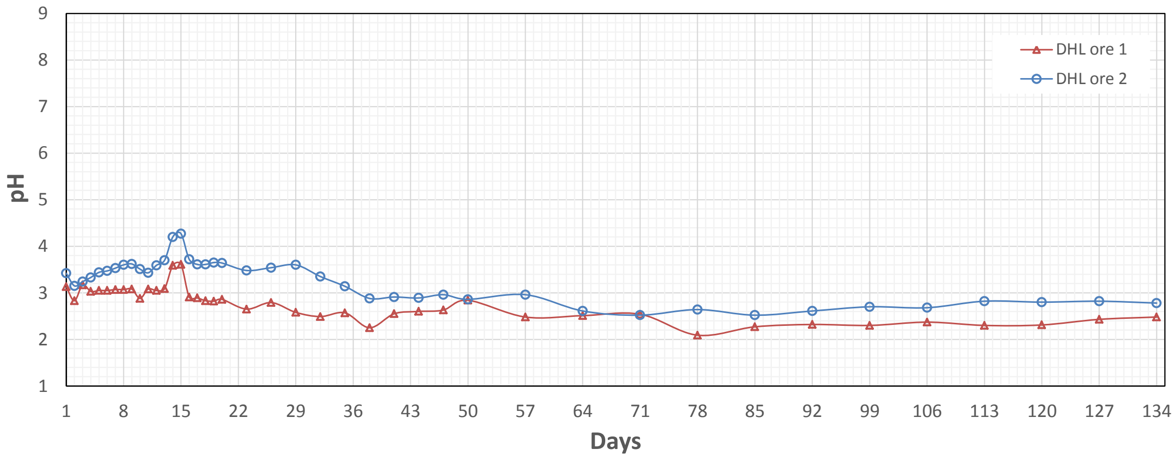

***Figure 1** Leachate pH of DHL Ore (Praseto, 2015)*

Kinetic testing for spent ore samples indicating residual alkalinity in the samples as shown in Figure 2. Lag time of approximately 29 days occurs for DHL spent ore 1 which is classified as high capacity PAF according to static test results. Different characteristics is shown for DHL spent ore 2 with more than three times longer lag time. Although it has low NAGpH this sample could be deemed as low capacity PAF due to small amount of Sulfur. Even during kinetic test it was previously predicted that this sample will not produce any acid leachates but after 92 days the leachate pH decreased drastically to 3. At the end (after 134 days) both spent ore samples produce similar leachates to the ore samples with pH values around 3.

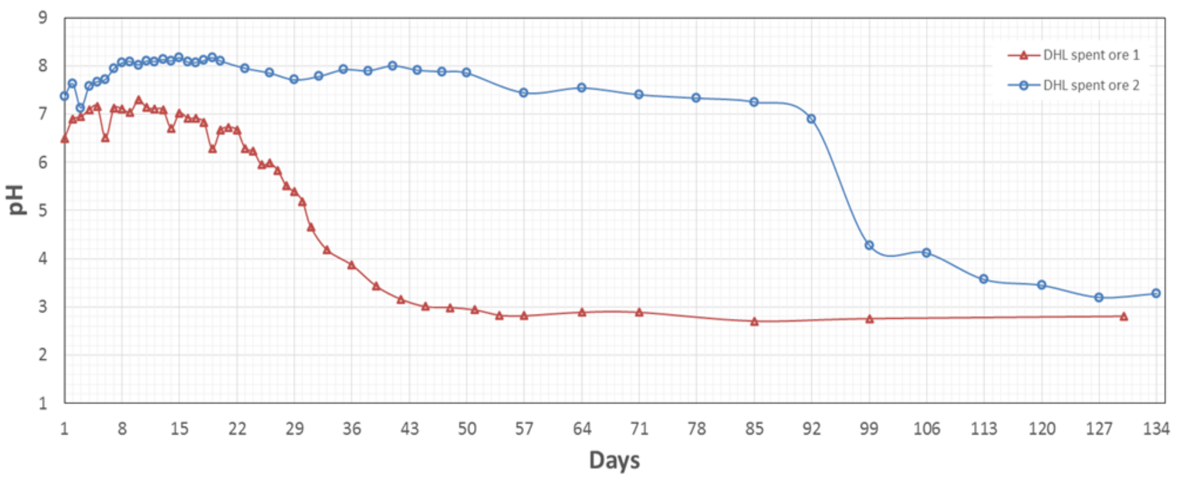

Figure 2 *Leachate pH of DHL Spent Ore*

According to Marsden & House (1992) iron sulfides could decompose in alkaline cyanide solutions to form iron cyanide complexes and various Sulfur species. However, the decomposition rate of pyrite in cyanide solutions is the lowest compare to arsenopyrite, marcasite and pyrrhotitte. It means that pyrite as the main source of AMD would not or only slightly change in the alkaline cyanide irrigation process It is confirmed with the results of spent ore characterization where both samples are still showing the potential to generate acid. The lag time in producing acid leachate during kinetic test could be interpreted as residual alkalinity in the spent ore fraction that is being washed by the time due to regular deionized water spraying.

This findings are important for the management of spent ore in the static heap leach plant. Ore characterization in AMD generation will not be changed after being irrigated by cyanide solution in the heaps meaning that PAF ore will still become PAF spent ore. Understanding the ore geochemical characteristics in AMD sensitive gold mine becomes important in developing proper spent ore management to minimize the environmental risk by preventing AMD generation.

b. Spent ore from multiple stacking heap leach

In multiple stacking heap leach, the ore for next leaching cycle will be stacked on the top of leached ore from previous cyanide irrigation and the leached ore will stay on the pad forever. During post closure the heap pad will be covered and rehabilitated. But we are fortunate because there is a plan to re-process the old heap since economic amount of gold is still be found in the spent ore. Re-excavation work of old heap provide the opportunity to take old spent ore samples that already in the leach pad for more than 10 years. Three spent ore samples (defined as SHL spent ore) were selected that represent the ore from oxidation zone.

The result of static tests for SHL spent ore is presented in Table 1. According to NAPP criteria, all samples are classified as PAF with high capacity (>100 kg H_2SO_4/ton of rock). This classification is also confirmed with NAG test results with NAGpH below 4.5.

Table 3 *Static Test Results of SHL Spent Ore Samples*

Sample Code	TS[%]	MPA*)	ANC*)	NAPP*)	NAG pH	NAG pH = 4.5*)	NAG pH = 7*)
SHL Spent Ore 1	7.39	226	<0.50	226	3.98	0.80	2.80
SHL Spent Ore 2	6.83	209	<0.50	209	2.71	34.30	41.10
SHL Spent Ore 3	6.23	191	2.70	188	2.80	20.70	29.40

Remarks: *) = in kg H_2SO_4/ton of rock; TS = Total Sulfur [%], MPA = Maximum Potential of Acidity, ANC = Acid Neutralizing Capacity, NAPP = Net Acid Producing Potential, NAG = Net Acid Generation

Respective ore samples were selected from core of oxidized zone in the mining area. They have quite similar characteristics to the spent ore and are deemed as PAF with high capacity (NAPP > 100 kg H_2SO_4/ton of rock and NAGpH < 3).

Table 4 *Static Test Results of SHL Ore Samples*

Sample Code	TS[%]	MPA*)	ANC*)	NAPP*)	NAG pH	NAG pH = 4.5*)	NAG pH = 7*)
SHL Ore 1	4.78	146	0	146.00	2.53	39.30	47.00
SHL Ore 2	11.60	355	0	354.96	2.32	79.50	91.10
SHL Ore 3	8.09	248	0	248.00	2.47	52.30	62.50

Remarks: *) = in kg H_2SO_4/ton of rock; TS = Total Sulfur [%], MPA = Maximum Potential of Acidity, ANC = Acid Neutralizing Capacity, NAPP = Net Acid Producing Potential, NAG = Net Acid Generation

Kinetic tests for both ore and spent ore samples were conducted for more than 55 days and the results are shown in Figure 3 and 4. While the ores are showing similar trend in leachates quality (pH value 1.5 to 3.4) which are in line with the static test results (PAF high capacity), the results for spent ore samples are showing different values, in particular spent ore 3 that is defined as high capacity PAF with NAPP = 288 kg H_2SO_4/ton of rock and NAGpH < 3.

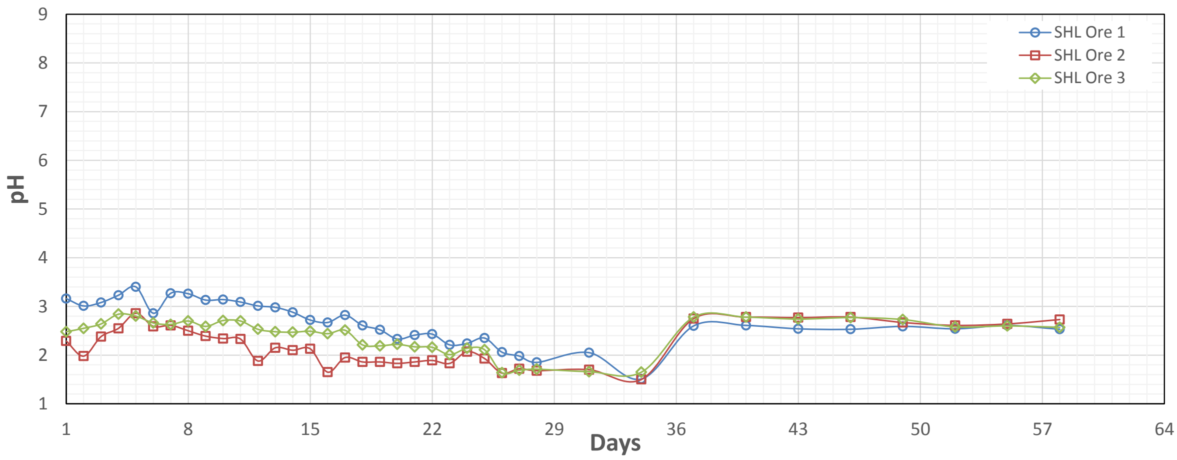

Figure 3 *Leachate pH of SHL ore*

Leachate pH values for SHL spent ore 3 are in the range of 6.8 to 8.1 compare to the acidic leachate values of other spent ore samples (see fig 4). Since the static testing result showing high capacity PAF, spent ore 3 sample seems to contain residual alkalinity from cyanide irrigation process similar to trend in dynamic heap leach. Longer kinetic testing up to 20 weeks would explain whether the alkaline characteristic is permanent or it is only residual alkalinity from the irrigation process.

There is similarity between SHL and DHL spent ores characteristics from AMD perspectives. Final leachates in kinetic testing indicated acid producing capacity of samples that confirmed with the results of static testing. Cyanide irrigation process would not change or, if any, only very small change, the geochemical characteristics in AMD generation of the ore in the leach pad.

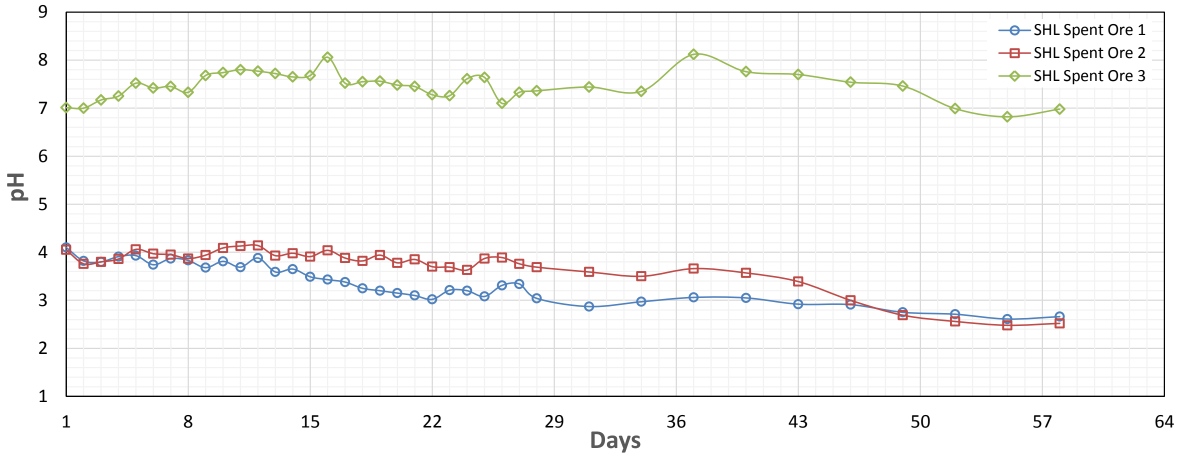

Figure 4 *Leachate pH of SHL spent ore.*

Conclusions

High sulfidation epithermal gold deposit is characterized by ore which is suitable for heap leaching process. Having abundance of sulfide minerals particularly in from weathering transition and fresh zones, acid mine/rock drainage is one of the important environmental issues in the mining operation of such deposit generated both by waste rock and ore. In an on-off or single stacking heap leach operation, the leached ore, defined as spent ore, will be removed from the pad and dumped together with waste rock and should be treated accordingly.

From the static testing criteria spent ore samples from dynamic or single stacking heap leach plant were classified as PAF, however, they have shown lag time in producing acid leachates during kinetic testing. There were indications of residual alkalinity from cyanide solution irrigation process which occurred in alkaline environment to optimize gold leaching process. It also could be concluded that only very small amount of pyrite have been decomposed during the cyanide irrigation process in the heap as shown in the final leachate pH of 3 after almost 20 weeks of column spraying which is similar to the leachate pH of ore columns. Similar results have been observed for spent ore samples from permanent or static heap leach operation.

The characterization of spent ore in dynamic heap leach operation is important in the AMD management of the mine. PAF spent ore should be placed accordingly to prevent the AMD generation. Encapsulation of PAF spent ore and PAF waste rock will be the best option in securing the long term reliability.

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