

Study of the Effect of Dissolved Oxygen Concentration on Gold Recovery Leaching at PT Indo Muro Kencana

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ABSTRACT. Gold is a very important metal in human life. Most gold is processed using the sodium cyanide (NaCN) leaching method. Maximizing the leaching recovery can be done by optimizing the leaching process parameters, one of which varies the concentration of dissolved oxygen (DO). Oxygen is added to oxidize gold atoms (Au) into cations (Au⁺) which will then react with cyanide ions (CN⁻) to form the aurocyanid complex anion Au(CN)₂⁻ dissolved in cyanide solution. This study aims to investigate the best method between the use of O₂, H₂O₂, and Aachen reactor in generating dissolved oxygen concentration to oxidize valuable metals. From the experimental results, which method can produce higher leaching recovery will be seen. Based on this study, the dissolved oxygen variation derived from oxygen injection (O₂) obtained a percent recovery of 92.5% Au and 80.5% Ag, hydrogen peroxide (H₂O₂) achieved a percent recovery of 92.5% Au and 79.9% Ag, and Aachen sheared (Aachen reactor) with a percent recovery of 95% Au and 81.9% Ag.

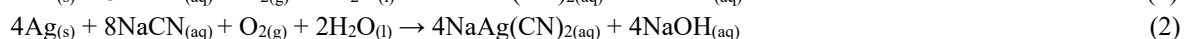
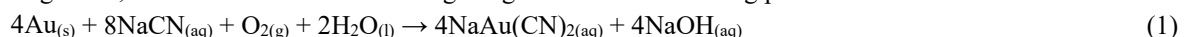
1. INTRODUCTION

Gold is a precious metal in human history, in addition to decoration, gold is widely used for technology. Gold can dissolve in oxidative environments with the help of leaching agents such as aqua regia, cyanide, thiosulfate, thiourea, and halide solutions to form complex compounds such as AuCl₂⁻, AuCl₄⁻, Au(CN)₂⁻, Au(S₂O₃)₃³⁻, and others. These leaching agents allow gold to be selectively extracted by hydrometallurgical methods from low-grade ores (<0.5 to 1.5 g/t Au) to produce higher metal purity (up to 999.9) [1-2].

The hydrometallurgical process is the process of extracting metals from their impurities at relatively low temperatures by leaching with the help of reagents [3]. One of the leaching methods that is often used in the hydrometallurgical process is the cyanidation method. The cyanidation method has been practiced since the 19th century and is the most widely used leach in the mining industry. This is because cyanide has a high leaching efficiency for the release of gold from its impurities, low cost, and high stability [4]. The cyanidation method can be carried out by several methods, including the agitation leaching method. Agitation leaching is a leaching process that uses an agitator to stir the slurry in a steel tank.

To optimize the leaching process, the oxidation process of valuable minerals can be carried out with the help of complexing agents such as (CN)⁻ cyanide ions [5]. Leaching agents that are often used in the cyanidation process are NaCN, KCN, Ca(CN)₂ or a mixture of the three. The cyanide will dissolve and ionize in solution into free cyanide (CN)⁻, then will bind to Au to form aurocyanid complex compounds [Au(CN)₂]⁻ and argentocyanid complex compounds [Ag(CN)₂]⁻ [6].

In general, the reactions that occur during the gold and silver leaching process are as follows:



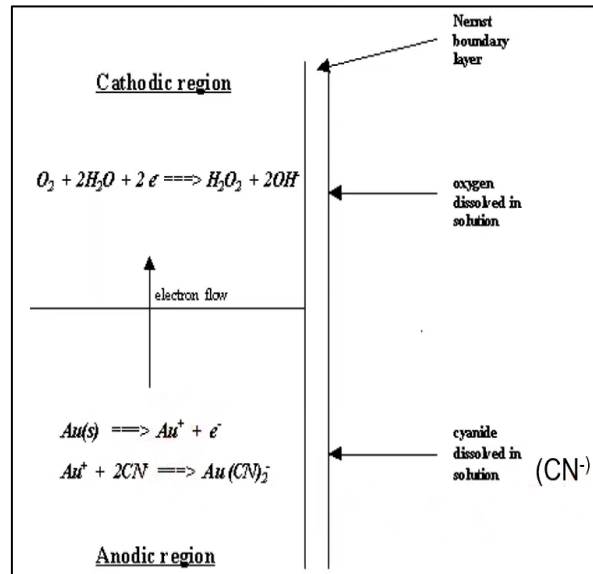
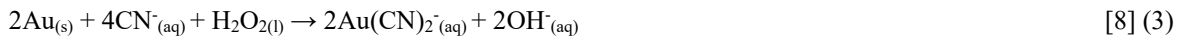


Figure 1. Mechanism of Au electrochemical leaching [7]

Oxygen is added to oxidize gold atoms (Au) into their cations (Au^+) which will then react with cyanide ions (CN^-) to form the aurocyanid complex anion $[\text{Au}(\text{CN})_2]^-$ dissolved in cyanide solution as in Figure 1. The oxygen used comes from air, O_2 -enriched air, pure oxygen, or hydrogen peroxides (H_2O_2). The reaction of peroxide (H_2O_2) with gold and cyanide is described as in reaction (3).



The adsorption process of gold and silver from complex compounds can be carried out using the carbon in leach (CIL) method, employing activated carbon as the adsorbent. Carbon in leach is one of the adsorption methods using activated carbon that is conducted during the leaching process by adding activated carbon into the leaching tank [9-10].

Table 1. Hydration numbers of cyanide atoms and estimated hydration numbers for cyanide complexes [1]

	Hydration number for cyanide N atom	Shape factor ^a	Estimated hydration number for cyanide complex
$\text{Zn}(\text{CN})_4^{2-}$	4.098	3.582	14.681
$\text{Hg}(\text{CN})_4^{2-}$	3.998	3.727	14.902
$\text{Cu}(\text{I})(\text{CN})_3^{2-}$	4.743	2.783	13.200
$\text{Hg}(\text{CN})_3^-$	3.576	2.898	10.336
$\text{Cu}(\text{I})(\text{CN})_2^-$	4.532	1.972	8.939
$\text{Ag}(\text{CN})_2^-$	3.838	1.998	7.669
$\text{Au}(\text{CN})_2^-$	3.767	1.995	7.513
$\text{Hg}(\text{CN})_2^-$	3.285	1.995	6.552

It can be calculated using formula (4) to determine the percentage of gold recovery.

$$\frac{\text{Au in Carbon}}{\text{Total Au Content from Ore}} \times 100\% \quad (4)$$

The dissolved substances in a solution will form complex compounds, a process commonly referred to as solvation (or hydration when the solvent is water) [11]. The hydration of complex metals is significant in gold hydrometallurgy, where an increased level of hydration leads to the enlargement of the complex's diameter. As a result, precious metals find it more difficult to enter the micropores of activated carbon, leading to a decrease in the adsorption of these precious metals [12]. The low hydration level of $[\text{Au}(\text{CN})_2]^-$ is a factor influencing the selectivity of $[\text{Au}(\text{CN})_2]^-$ adsorption onto activated carbon when compared to other metals [13]. Based on research

conducted by Yin et al. [12] and Ghasemi et al. [14], it is concluded that complex carbon adsorption increases with a decrease in the hydration number of complex metals, as shown in Table 1.

2. MATERIAL AND METHODS

2.1 Materials

The samples used are slurry samples from the leaching process at the PT Indo Muro Kencana factory with a P_{80} size of 75 μm . Samples were taken at two points, namely the inlet of leach tank 1 as much as 10000 ml and the outlet of leach tank 1 as much as 5000 ml. To determine the content of valuable metals in the sample using Atomic Absorption Spectrometry (AAS). In addition, 10 g/l activated carbon, 21 ppm oxygen, 97% rhodanine (Sigma-Aldrich), AgNO_3 , 30% w/w H_2O_2 (Analytical Reagent), 98% NaCN (Taekwang IND.CO) were required.

2.2 Tools

The tools used in this research include a leaching reactor, agitator, stone aerator, pH meter (YSI Pro10), dissolved oxygen (DO) meter (YSI Pro20), vacuum filter, burette, beaker, Erlenmeyer flask, measuring tube, sieve, spatula, scale and sample bottle.

2.3 Research Variables

This study uses three dissolved oxygen source variables for each reactor, namely:

1. The first reactor DO used comes from O_2 (from an oxygen cylinder)
2. The second reactor DO used comes from H_2O_2 (hydrogen peroxide)
3. The third reactor DO used comes from the factory's Aachen device (Aachen Sheared).

2.4 Methods

2.4.1 Head grade and sampling

Head grade samples from each variation were taken as many as 3 samples of 50 ml each to analyze the initial gold and silver content using the fire assay method. Then sampling was carried out at hours 2, 4, 8, 24, 32, and 48, with a sampling of 150 ml of slurry and solid liquid separation using a vacuum filter. Solid is analyzed by the fire assay method and solution with AAS to analyze the gold and silver content at each time interval of each reactor. While carbon samples were taken at the 48th hour to analyze the gold and silver content in nature using Atomic Absorption Spectroscopy (AAS) by Shimadzu (Japan).

2.4.2 Leaching variation of O_2 and H_2O_2

The samples used for the O_2 reactor and H_2O_2 reactor were taken from the inlet of leach tank 1 as much as 5000 ml for each reactor. The samples taken are measured using a measuring cup and then inserted into the leaching reactor that has been assembled as in Figure 2. In the O_2 reactor only oxygen is flowed while for the H_2O_2 reactor oxygen is flowed with the addition of H_2O_2 .

Furthermore, the leaching preparation is carried out by assembling as in Figure 2. Reactors that have been paired with aerator stones and oxygen are rotated using an agitator at a speed of about 200 rpm. Cyanide reagent is added after adjusting the pH with the addition of lime until it reaches 10.2-10.5 and DO by increasing the entry rate by 15-20 ppm.

2.4.3 Leaching variation of Aachen Sheared

The sample used for the Aachen Sheared reactor came from the outlet of leach tank 1 at the company's factory. Samples taken as much as 4550 ml adjust the amount of sample residue in the other two reactors after sampling. The samples taken have undergone a leaching process for 8 hours, just like the other two reactors. The DO source used in the Aachen Sheared reactor sample came from the Aachen device installed in leach tank 1.

2.4.4 Adsorption of precious metals

Activated carbon was added for the adsorption process of gold and silver from the solution. Activated carbon was added at the 16th hour for each reactor as much as 10 gpl.

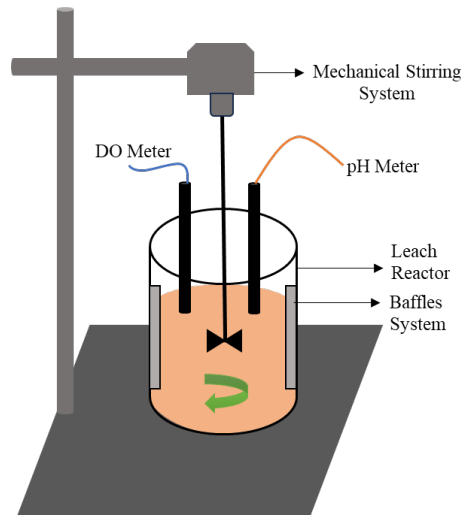


Figure 2. Sequence of Leaching Process

3. RESULT AND DISCUSSION

The experiment used sodium cyanide (NaCN) reagent because of its ability to form aurocyanid $[\text{Au}(\text{CN})_2]^-$ and argentocyanid $[\text{Ag}(\text{CN})_2]^-$ complex ions that are very stable [15] with variations in dissolved oxygen (DO). This experiment was conducted for 48 hours with sampling time intervals at 2, 4, 8, 24, 32 and 48 hours. Activated carbon was added at 16 hours as much as 10 gpl. Other parameters were kept constant with conditions: pH 10.20 - 10.50, solid percent 42%, dissolve oxygen 20 ppm. The pH and dissolved oxygen (DO) conditions were kept stable during the leaching process (hour 0 to hour 8).

Gold leaching and gold adsorption from the solution are influenced by several factors, one of which is the level of dissolved oxygen concentration in the slurry. Oxygen in the slurry will oxidize the gold atom (Au) into its cation (Au^+) so that it can react with cyanide ions (CN^-) to form an aurocyanid complex anion $[\text{Au}(\text{CN})_2]^-$ which is dissolved in a cyanide solution. The experiment was conducted with 3 (three) variations of dissolved oxygen consisting of pure O_2 injection, H_2O_2 , and pure O_2 injection with the help of Aachen reactor to distribute oxygen. From the experiment, a comparison of the percent gain of the three was obtained as shown in Figure 3.

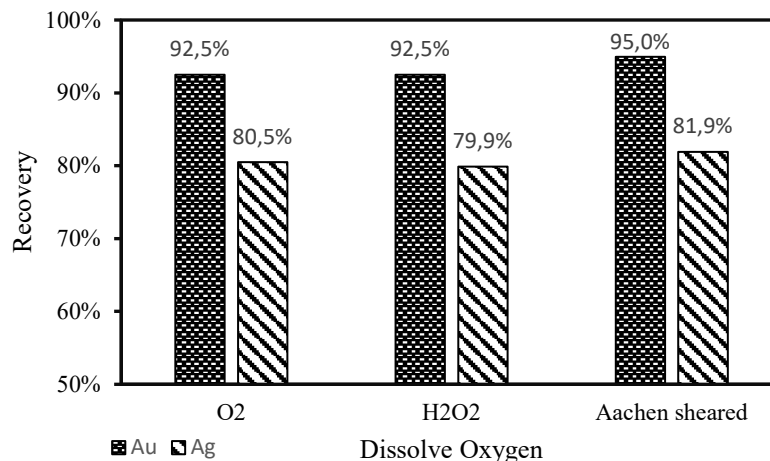


Figure 3. Percentage Extraction of Gold and Silver with Respect to Dissolved Oxygen from O_2 , H_2O_2 , and Aachen Sheared over 48 hours

Based on Figure 3, we can see the difference in recovery from the three reactors used. In the O_2 reactor, the leaching process utilizes oxygen sourced from an oxygen cylinder. The oxygen introduced will help the leaching process by oxidizing gold as in reaction (1) and silver as in reaction (2). Oxygen is introduced through an aerator stone to produce oxygen in the form of small bubbles that can be observed directly during the experiment. The air

bubbles are evenly distributed in the slurry for 8 hours of injection and are kept at a level of 20 ppm (maximum measurement by DO meter). From the final results, a recovery of 92.5% Au and 80.5% Ag was obtained.

In the H_2O_2 reactor, the leaching process is carried out with oxygen sourced from oxygen injection from an oxygen cylinder and hydrogen peroxide (H_2O_2). Hydrogen peroxide can increase dissolved oxygen in the slurry, by oxidizing gold as in reaction (3). The addition of hydrogen peroxide can be used as an oxygen precursor so that it can be an alternative to oxygen as a gold oxidizing agent [16]. Hydrogen peroxide was added at the second hour as much as 1 ml and at the 4th hour as much as 2 ml. From the final results, the recovery from the H_2O_2 reactor was 92.5% Au and 79.9% Ag.

For the Aachen sheared reactor, the slurry used comes from the outlet of leach tank 1 which has undergone a leaching process for approximately 8 hours in tank 1. In tank 1 leaching, the slurry sample has been oxidized by oxygen coming from the Aachen reactor. Aachen reactor is designed with the concept of friction, where the slurry will be pumped into the reactor and at the same time high speed air will flow perpendicular to the slurry flow. The high friction generated between air and slurry when passing through the Aachen reactor will increase the reaction of the solids interface to be faster than without the Aachen reactor [17]. From the final results, the recovery for the sheared Aachen reactor was 95% Au and 81.9% Ag. The recovery of Au in the Aachen sheared reactor is higher than the O_2 reactor and H_2O_2 reactor, which increased by 2.5% Au and 1.9% Ag according to the calculation in equation (4). This is influenced by the different treatments in the three leaching processes.

The Aachen sheared reactor undergoes a leaching process first in the leach tank at the factory for 8 hours with the cyanide concentration maintained. In addition, with the help of the Aachen reactor tool which can increase the DO concentration in the slurry so that it can accelerate the leaching rate. As for the O_2 and H_2O_2 reactors, the leaching process in the laboratory-scale reactor tank does not experience maintenance of the cyanide concentration during the process. In addition, the effect of adding H_2O_2 and O_2 injection can increase the oxygen concentration in the slurry.

The concentration of dissolved oxygen in the slurry greatly affects the gold cyanidation process. The higher the concentration of dissolved oxygen, the faster the leaching rate will be because it increases the release of valuable metals [16-18]. Increasing the concentration of dissolved oxygen in the solution can be done by increasing the concentration of dissolved oxygen and using oxygen with a higher purity level. In addition, an Aachen reactor can be used to promote more intensive aeration into the solution. Aachen reactor can produce smaller bubbles so that oxygen is more easily dispersed in the slurry. With the help of Aachen reactor can produce a DO concentration of 28 -32 ppm.

After analyzing cyanide consumption against variations in dissolved oxygen concentration, different cyanide consumption was obtained in the O_2 reactor and H_2O_2 reactor as shown in Figure 4. Cyanide consumption in the O_2 variation was 2.47 grams and the H_2O_2 variation was 2.29 grams. The cyanide consumption used in the H_2O_2 reactor is less when compared to the cyanide consumption in the O_2 reactor.

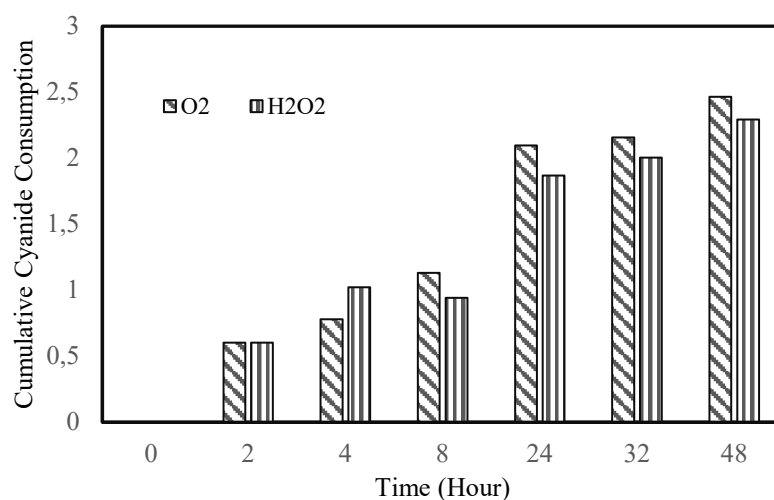


Figure 4. Cumulative Cyanide Consumption over Leaching Time in the O_2 Reactor and H_2O_2 Reactor for 48 hours

From the analysis of cyanide consumption in the Aachen sheared reactor in the period from hour 8 to hour 48, the cyanide consumption was 2.16 grams. Figure 5 only shows the cyanide consumption in the Aachen sheared reactor, because there are differences in the treatment given to the CIL test process.

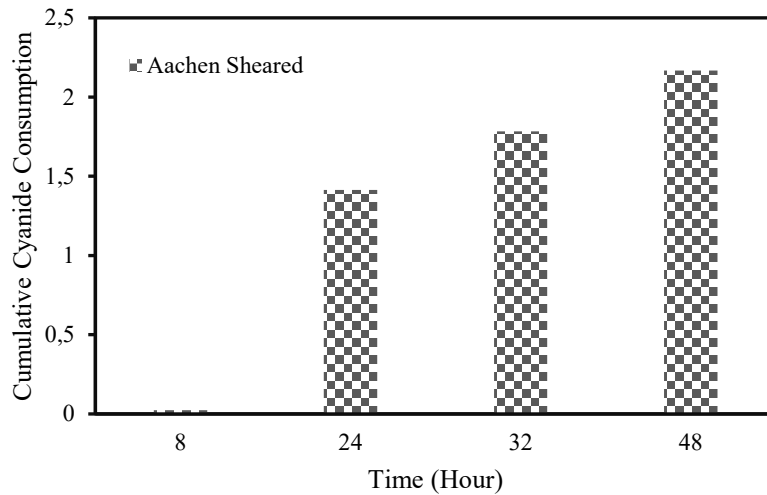


Figure 5. Cumulative Cyanide Consumption over Leaching Time in the Aachen Sheared Reactor from hour 8 to hour 48

Various factors can influence cyanide consumption. One factor is the mineralogy of the ore, including the presence of chalcopyrite, pyrite, and quartz, which can form various cyanide complexes and precipitate them [19]. In addition, during the leaching process, cyanide loss can occur because the pH of the slurry influences it during leaching. If the pH is around 9.3, half of the total cyanide will react into hydrogen cyanide (HCN) and half as free cyanide ions (CN⁻) [15]. Therefore, the pH needs to be maintained at the optimal range to prevent cyanide from being released into the air, namely by adding lime until it reaches the optimal pH range.

In addition, cyanide concentration is also very influential on the gold cyanidation process. A low cyanide concentration will cause the leaching reaction of valuable minerals to not run optimally, while if the cyanide concentration is too high, the cyanide can react with other metals contained in the ore so that valuable minerals cannot be absorbed properly by activated carbon during the adsorption process. At high NaCN concentrations, the oxygen concentration will increase and accelerate the rate of leaching of valuable minerals and increase recovery [20].

4. CONCLUSION

Based on the results and discussions above, varying the concentration of dissolved oxygen in the leaching process yields the following conclusions:

1. The higher the DO concentration, the faster the gold and silver leaching rate and the higher the recovery.
2. NaCN reagent consumption for the O₂ reactor amounted to 2.47 grams and H₂O₂ with a reagent consumption of 2.29 grams calculated from the 0th hour to the 48th hour, while the reagent consumption for the Aachen sheared reactor amounted to 2.16 grams calculated from the 8th hour to the 48th, which has undergone a leaching process in the tank at the plant for 8 hours.
3. Based on the results of data processing, it is concluded that the % recovery of gold and silver in the O₂ reactor is 92.5% Au and 80.5% Ag, the H₂O₂ reactor is 92.5% Au and 79.9% Ag, while the Aachen sheared reactor is 95% Au and 91.6% Ag.

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