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Contribution of Aachen High Shear Reactor & Filblast Low Shear Reactor as Gold Ore Pre-Treatment Leaching at Geoservices (Ltd.)

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Abstract. *Gold (Au) as a precious metal has played significant role throughout human history. Most gold ores subjected to leaching using the sodium cyanide (NaCN) contain high levels of base metals. High base metal content can influence the recovery of pregnant leach solution (PLS), as it affects the consumption of sodium cyanide (NaCN) and lime used to optimize the gold ore leaching process. Pre treatment leaching process is required for gold ores before the leaching process is carried out. In this study, a pre treatment leaching process was carried out using the Aachen High Shear and Filblast Low Shear Reactors with variations in feed solids percentage for each reactor, utilizing NaCN concentrations of 1000 ppm for the Aachen with bottle roll test (BRT) and 500 ppm for the Filblast with agitations leach test (ALT). Based on this study, each pre-treatment leaching reactor, the extraction percentages were 54.30% Au, 63,40% Ag for the Aachen and 52.19% Au and 68,10% Ag at Filblast. Lime consumption in the Aachen was highest at 3.47 kg/t (PreOx 3 and AAL), while in Filblast at 1.71 kg/t. Meanwhile, NaCN consumption in the Aachen was highest at 0.64 kg/t (PreOx 2), compared to 0.80 kg/t in Filblast.*

Keywords: *Gold, Pre-treatment Leaching, Aachen Reactor, Filblast Reactor, Percent Extraction.*

1. INTRODUCTION

Gold (Au) as a precious metal has played significant role throughout human history, is utilized not only for decorative purposes but also extensively in technology applications (Manning & Kappes, 2016). Gold can dissolves in oxidative envirements through the use of leaching agents such as aqua regia, cyanide, thiosulfate, thiourea, and halide solutions, forming complex compounds such as $AuCl_2^-$, $AuCl_4^-$, $Au(CN)_2^-$, $Au(S_2O_3)_3^{2-}$ (Niu et al., 2023). Hydrometallurgy refers to the extraction of metals from their ores or impurities using leaching processes at relative low temperatures by specific reagents (Aylmore, 2016). Among these methods, cyanidation has been widely adopted and remains the most commonly technique in the mining industry. This widespread use is attributed to cyanide's high efficiency in dissolving gold, low operational cost, and remarkable stability (Qin et al., 2021). Cyanidation can be implemented using various techniques including agitation leaching, it involves stirring a slurry mixture in a steel tank using an agitator to enchance the leaching process (F. Zhang et al., 2023).

Geoservices (Ltd.) has established itself as a company providing exploration and analytical services for various industrial sectors. Initially based in Bandung, West Java, Geoservices has steadily expand its operational coverage. It now operates branch offices in Jakarta, Indonesia and Singapore, with additional offices strategically located across Indonesia to enchane service accessibility for prospective clients. Specifically, the GeoAssay Mineral

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Laboratory in Cikarang, West Java, hosts a Metallurgy Division dedicated to introducting analysis and test work, particularly in areas ranging fromsample preparation to leaching processes, especially for gold ores (CELEP et al., 2009). During leaching process, challenges often arise regarding excessive reagent consumption and low extraction percentrages, as informed by the ongoing characterization of provides pre-treatment leaching methods, equipped with technology such as the Aachen High Shear Reactor and Filblast Low Shear Reactor (Saba et al., 2011).

Most ores subjected to leaching contain high levels of base metals. High base metal content can influence the recovery of pregnant leach solution (PLS), as it affects the consumption of sodium cyanide (NaCN) and lime used to optimize the gold ore leaching process (Surimbayev et al., 2024). Therefore, testing is needed to determine the maximum extraction percentage achievable from ore, while considering its base metal content. This is crucial for estimating the concentration of gold enriched solution produced when the ore undergoes leaching on cells (Wu et al., 2025).

Methods to address minerals that reduce leaching efficiency, or hinder the process known as pre-treatment leaching can significantly improve the overall leaching effiftiveness. Testing is conducted with variations in feed solids percentage for each reactor, utilizing NaCN concentrations of 1000 ppm for the Aachen reactor and 500 ppm for the Filblast reactor (Kasaini et al., 2008). Following this, the bottle roll test (BRT) is applied for the Aachen reactor and the agitiation leach test (ALT) for the Filblast reactor (H. Li et al., 2018). Results indicated that pre-treatment leaching using reactors designed to apply shearing force enhances gold extraction percentage. However, if a low extraction percentrage is achieved alongside high NaCN consumption, it suggests that the ore contains high levels of base metals, leading to NaCN absoroption by these base metals, reducing its availability as a gold leaching agent (Hapid et al., 2024).

2. LITERATURE REVIEW

Importance of Pre-Treatment Leaching Techniques

Refractory gold ores, which contain minerals like sulfides, often demand pre-treatment to improve extraction efficiency (Korolev et al., 2022). Techniques like roasting and bio-oxidation modify minerals surfaces, making gold eccessible for cyanidation process. At Geoservices (Ltd.), equipment such as Aachen High Shear Reactor and Filblast Low Shear Reactor employed to optimize dissolved oxygen (DO) and reagent interaction with particles, which aligns the need for advanced agitation and oxidative environments (K. Zhang et al., 2020).

Hydrometallurgical Processing

The cyanidation remains the gold ores standard in hydrometallurgical recovery. Recent studies have underscored the significance of DO and agitation in gold dissolution accelerate rates (X. Zhang et al., 2024). The implementation of Aachen and Filblast Reactors aligns with focusing on high shear forces to enchane DO, as shown in other studies utilizing high shearing and mixing technologies (K. Li et al., 2023).

Reagent Consumption and Environmental Considerations

Minimizing reagent consumption without compromising gold recovery is a objective key. High cyanide concentrations often lead to secondary reactions with base metals, reducing efficiency (Kohio et al., 2024). Innovations like Aachen reactors address this by maintaining optimal cyanide to oxygen ratios, reducing waste while improving recovery percentages (Celep et al., 2011).

3. METHODS

Sample Preparation

In the pre-treatment leaching process, different NaCN concentrations were utilized in each reactor, following standart guidelin In this research, several steps were undertaken to obtain the necessary data for compiling the research findings (Wills & Finch, 2016a). Therefore, sample preparation and characterization according to the required sizes for testing were essential. The preparation steps included dewatering, drying, comminution, and splitting & homogenizing for uniformity (Wills & Finch, 2016b).

1. Dewatering

   The sample used consisted of 170 liters and was still in slurry form. Dewatering was performed to separate the solids from the solution in the slurry using a filter press, resulting in two products: a solid "cake" and a liquid solution. The dewatering process took approximately 2 hours, primarily due to the high solid content within the slurry.
2. Drying

   The dewatering process yields a solid product (cake) along with a solution. Subsequently, the cake obtained from the dewatering stage undergoes a drying process at a temperature of 60°C for a duration of 24 hours. The purpose of this drying process is to reduce the moisture content in the cake, resulting in a final product with an exceptionally low moisture level.

3. Splitting and Homogenizing

   After particle size reduction, the sample undergoes a homogenization and separation process using a rotary sample divider (RSD) to obtain a uniform sample. This process begins by pouring the crushed sample into the RSD feeding hopper, followed by adjusting the vibration intensity and rotation speed of the pan where the sample falls. Splitting and homogenizing are performed with three repetitions to achieve a uniform sample. The repetition process must be carefully managed by reintroducing the sample from the pan opposite back into the RSD feeding hopper.

Pre-Treatment Leaching: Aachen High Shear Reactor

1. Sample Preparation: Prepare 30 kg of solid material and 48 liters of water to create a slurry with a 40% solid concentration. Ensure all slurry is fully homogenized before transferring it to the reactor tank, with the agitator active to maintain uniformity.
2. Equipment Preparation: Before beginning pre-treatment in the Aachen reactor, calibrate the equipment according to standard operating procedures.
3. Homogenization and Sampling: After homogenization, sample 1 liter of slurry from the side valve to check the specific gravity (SG) of the sediment.
4. Baseline Stage: Circulate the slurry through the Aachen reactor three times without injecting oxygen and without pH adjustment. Maintain the initial slurry condition as the "Baseline Stage" and monitor pH, dissolved oxygen (DO), oxygen pressure, oxygen flow rate, slurry pressure, and oxygen pressure at each pass.
5. Pre-Oxidation Stage: Transfer oxygen flow to the Aachen reactor system. Adjust pH to 10.5–11 using lime before starting the Pre-Oxidation Stage. Recirculate the slurry through the reactor three times, monitoring pH, DO, oxygen pressure, oxygen flow rate, and slurry pressure after each pass.
6. AAL Stage: In the subsequent AAL Stage, add sodium cyanide (NaCN) to the slurry at a concentration of 500 ppm. Recirculate the slurry through the reactor three times, conducting the same pH, DO, oxygen pressure, oxygen flow rate, and slurry pressure measurements at each pass.
7. Sampling During Process: Take 1-liter samples at each stage for further testing using the BRT method over a 24-hour period. Additional sampling intervals at 0, 2, 4, 8, 12, and 24 hours involve checking pH, DO, oxygen pressure, oxygen flow rate, slurry pressure, and oxygen pressure.

Pre-Treatment Leaching: Filblast Low Shear Reactor

1. Sample Preparation: Prepare 40 kg of solid material and 47 liters of water to create a slurry with a 46% solid concentration. Ensure all slurry is fully homogenized before transferring it to the reactor tank, with the agitator active to maintain uniformity.
2. Equipment Preparation: Before beginning pre-treatment in the Filblast reactor, calibrate the equipment according to standard operating procedures.
3. Homogenization and Sampling: After homogenization, sample 1 liter of slurry from the side valve to check the specific gravity (SG) of the sediment.
4. Circulating Stage: Add sodium cyanide (NaCN) at a concentration of 1000 ppm and inject oxygen to the slurry. Circulate the slurry through the reactor three times, conducting the same pH, DO, oxygen pressure, oxygen flow rate, and slurry pressure measurements at each pass.
5. Sampling During Process: Take 1-liter samples at each stage for further testing using the ALT method over a 20-hour period. Additional sampling intervals at 0, 1, 2, 3, 4, 6, 8, and 20 hours involve checking pH, DO, oxygen pressure, oxygen flow rate, slurry pressure, and oxygen pressure.

Sample Head Assay

Before beginning the research, it is necessary to determine the head assay of each sample to establish the initial ore grade as a reference point for subsequent analysis. The assays employed include fire assay (FA) with a detection limit of 0.01 ppm and an upper limit of 50 ppm for gold (Au). Additionally, inductively coupled plasma (ICP) analysis is used, with a detection limit of 0.5 ppm and an upper limit of 1000 ppm for silver (Ag), and a detection limit of 1 ppm with an upper limit of 10,000 ppm for copper (Cu).

Preagnant Leach Solution (PLS) Assay

The pregnant leach solution (PLS) produced from the tests using both the Aachen reactor and the Filblast reactor will be analyzed through solvent extraction (SX) and atomic absorption spectroscopy (AAS) to determine its composition. For the PLS obtained from the Aachen reactor at each time interval, gold (Au) content was found to be <0.02 mg/L (below 0.02 ppm) based on SX testing. This SX test, conducted on PLS from the Aachen reactor process, has a detection limit of 0.02 mg/L, with a minimum detection threshold of zero ("0"). Additionally, AAS testing is performed to measure silver (Ag) and copper (Cu) concentrations in the PLS, with a detection limit set at 0.1 mg/L and a minimum detection threshold also at zero ("0").

The PLS results from testing the Filblast reactor at each time interval indicate an upward trend in Au concentration. During the initial phase of the process at 0.02 hours (65 seconds), a concentration of 0.33 mg/L was obtained, which increased to 0.40 mg/L after 20 hours of processing.

Tailing and Residue Assay

The extended process of the Aachen reactor, known as BRT, utilizes samples from the final slurry of the process, which have settled at the bottom of the container, referred to as "tail." The tail undergoes a filter press process to reduce its water content, making it suitable for further analysis through fire assay to determine its elemental composition. The results of the fire assay, inductively coupled plasma (ICP) analysis, and LECO analysis on the tail are collectively known as the tail assay.

Similarly, the Filblast reactor's extended process, called ALT, also uses the final slurry, with the settled material at the bottom of the container designated as tail. The tail is subjected to the filter press process to decrease water content, preparing it for the fire assay, which provides insight into its composition.

4. RESULTS

Based on the research conducted, the experimental data obtained showed the following results. The Au extraction percentage for the Filblast reactor was 52.19%, and for the Aachen reactor, the Au extraction percentrages for each process segmentation baseline, PreOx 1, PreOx 2, PreOx 3, and AAL were 53.5%, 53.5%, 52.7%, 54.3%, and 53.6%, respectively. The highest Au extraction percentage was achieved in the PreOx 3 segmentation, at 54.3%. The total Au extraction percentages for each reactor, presented in a comparison table, are shown in Figure 1.

Similarly, the silver (Ag) extraction data for the Filblast reactor was 68.1%, while for the Aachen reactor, the Ag extraction percentages for each process segmentation—baseline, PreOx 1, PreOx 2, PreOx 3, and AAL—were 61.5%, 62.8%, 62.1%, 62.2%, and 63.4%, respectively. The highest Ag extraction percentage occurred in the AAL segmentation, at 63.4%. The total Ag extraction percentages for each reactor, presented in a comparison table, can be seen in Figure 2.

Regarding copper (Cu), the Filblast reactor achieved a Cu extraction percentage of 49.0%, and for the Aachen reactor, the Cu extraction percentages for the process segmentations—baseline, PreOx 1, PreOx 2, PreOx 3, and AAL—were 51.1%, 53.4%, 50.6%, 47.7%, and 54.4%, respectively. The highest Cu extraction percentage was recorded in the

AAL segmentation, at 54.4%. The total Cu extraction percentages for each reactor, presented in a comparison table, are shown in Figure 3.

During the testing process, lime was added during the conditioning stage and at each pH check in each reactor process. The addition of lime was intended to condition and maintain the pH within the target range of 10.5-11. The lime consumption for the Filblast reactor was 1.71 kg/t, while for each segmentation in the Aachen reactor, the lime consumption was 2.95 kg/t, 3.15 kg/t, 3.02 kg/t, 3.47 kg/t, and 3.47 kg/t, respectively. The highest lime consumption in the Aachen reactor occurred in the PreOx 3 and AAL segmentations, both at 3.47 kg/t. The total lime consumption for each reactor, presented in a comparison table, can be seen in Figure 4.

In addition to lime, cyanide was also added for the leaching of Au, Ag, and Cu during the tests. The cyanide consumption for the Filblast reactor was 0.80 kg/t, while for each segmentation in the Aachen reactor, cyanide consumption was 0.65 kg/t, 0.63 kg/t, 0.64 kg/t, 0.60 kg/t, and 0.55 kg/t, respectively. The highest cyanide consumption in the Aachen reactor occurred in the baseline segmentation, at 0.65 kg/t. The total cyanide consumption for each reactor, presented in a comparison table, can be seen in Figure 5.

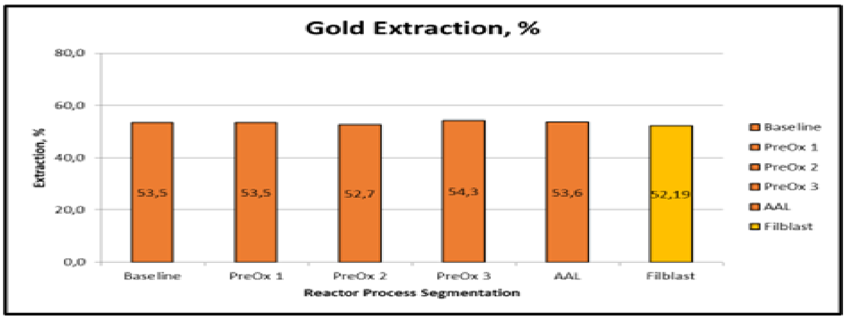

Figure 1. Total ratio %Au extraction

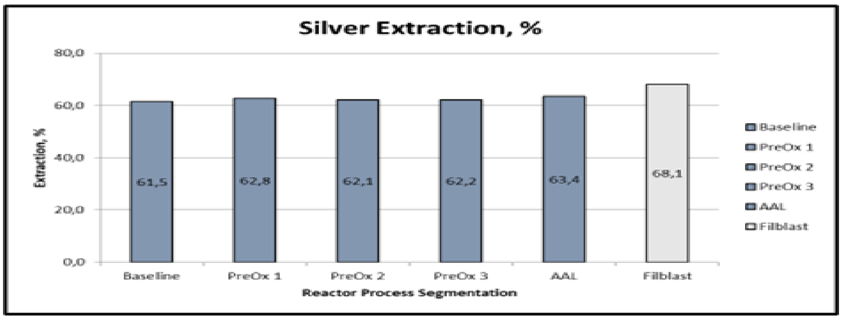

Figure 2. Total ratio %Ag extraction

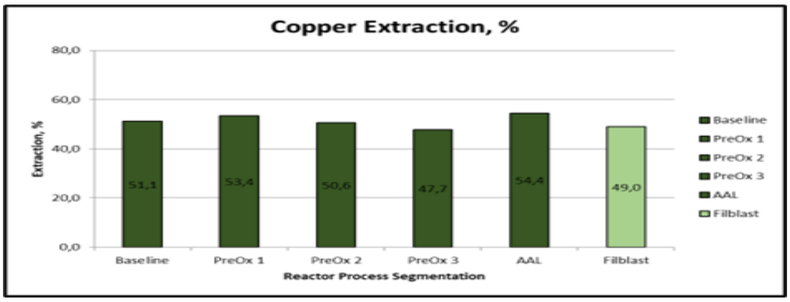

Figure 3. Total ratio %Cu extraction

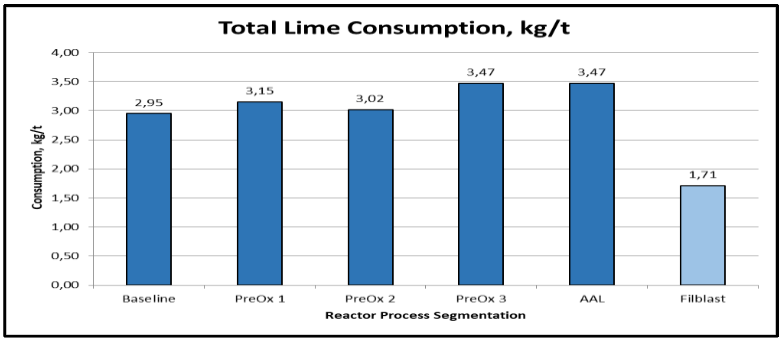

Figure 4. Total lime consumptions

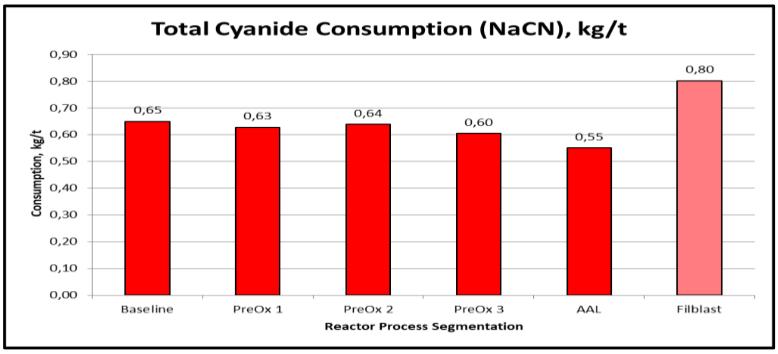

Figure 5. Total cyanide consumptions

5. DISCUSSION

Contribution of Pre-Treatment Reactors to %Extraction

In the pre-treatment leaching process, different NaCN concentrations were utilized in each reactor, following standart guidelines and varied subsequent processes. The NaCN concentration for the Aachen reactor involved the bottle roll test (BRT), whereas for the Filblast reactor, it was the agitation leach test (ALT). Each pre-treatment process lasted 20 hours, followed by and additional 24 hours subsequent treatment, to assess the contribution of each pre-treatment reactor to the %extraction result, specifically for gold (Au), silver (Ag), dan copper (Cu), as well as to compare reagent condumption, with NaCN being used as the leaching agent.

In operating the Aachen reactor, segmentation of prosses is critical, as each segment has distinct mechanisms and non-cumulative results. The Aachen reactor comprises Bseline, Pre-Oxidation, and Aachen Assisted Leaching (AAL) stages. The Baseline stage prepares the sample under base case conditions, while the Pre-Oxidation stage introduces a reductive gas, such as oxygen as in this study, into the slurry to oxidize potentially interfering minerals. The AAL stage, aimed at leaching gold, involves adding NaCN at a 500 ppm concentrations to the slurry.

Unlike the segmented process in the Aachen reactor, the Filblast reactor does not officially segment its process despite inherent mechanism by procedural steps. Initially, the sample undergoes preparations, followed by simultaneous oxygen injection and NaCN addition 1000 ppm to the slurry, initiating the leaching process concurrently with the gas injection.

Another notable difference lies in the shear force mechanism, determined by pressure levels. The Aachen reactor functions as a high shear reactor with high pressure shear force, whereas the Filblast reactor at Metallurgy Division Geoservices (Ltd.) operates under low pressure and low shear conditions.

Experimental result showed Au extraction for the Filblast reactor at 52.19% and for the Aachen reactor at 54.3% during third Pre-Oxidation stage. Since the Aachen reactor stages involve distinct processes, extraction result are non-aggregable, contrasting with single process emphasizing its advantage. Figure 1. illustrates the comparative %Au extraction both pre-treatment reactors.

In this study, the %Ag extraction achieved through pre-treatment processes yielded a result of 68.1% using the Filblast reactor. In comparison, the highest result obtained with the Aachen reactor was 63.4% in the AAL stage. Based on these findings, it can be concluded that the Filblast reactor outperformed the Aachen reactor by a margin of 4.7%. Acomparative analysis of the %Ag extraction rates for each pre-treatment reactor is presented in Figure 2.

In the pre-treatment method for Cu extraction, tha Filblast reactor achieved and extraction rate of 49.0%, while the Aachen reactor reach 54.4%, resulting in difference of 5.4%. The comparative%Cu extraction for each pre-treatment reactor is illustrated in Figure 3.

According to the comparative data on %extraction rates of Au, Ag, and Cu obtained from the experiments, the performance difference between the Aachen high shear reactor and the Filblast low shear reactor is not notably substantial. For %Au extraction, the Aachen reactor achieved 54.3%, while the Filblast reactor reached 52.19%, yielding a marginal difference of 2.11%, indicating that the Aachen reactor offers a 2.11% higher Au extraction rate. In the case of %Ag extraction, the Filblast reactor demonstrated a slight advantage with 68.1%, compared to 63.4% for the Aachen reactor, presenting a difference of 4.6%, which implies the Filblast reactor is 4.6% more effective for Ag extraction. For Cu extraction, the Aachen reactor achieved 54.4%, whereas the Filblast reactor achieved 49.0%, giving a 5.4% higher extraction rate for the Aachen reactor. The data illustrating these comparisons in %extraction rates of Au, Ag, and Cu across both reactors are presented in Figure 4.

Lime Consumption Comparison

In during the pre-treatment leaching tests utilizing the Aachen and Filblast reactors, lime was added during the conditioning stage and at each pH check in both reactor processes. Lime functions as a pH conditioning reagent for the slurry throughout the leaching process, including the current pre-treatment leaching phase. The addition of lime aims to maintain a consistent target pH between 10.5 and 11.

Data on lime consumption from each reactor was obtained through different methods. In the Aachen reactor, lime consumption data was calculated by summing the amounts added as a pH conditioning reagent. This conditioning was conducted during pre-treatment leaching in the Aachen reactor with lime added to control pH in the subsequent BRT leaching process. Lime consumption was cumulatively measured for both the pre-treatment stage in the reactor and its subsequent processes. The formula used for calculating the total lime consumption in the Aachen reactor’s pre-treatment sequence is shown in Table 1.

Based on these calculations, accumulated lime consumption data for the pre-treatment process in the Aachen reactor and subsequent BRT phase was obtained. Similarly, lime consumption in the Filblast reactor was calculated alongside its continuation process, ALT. Accumulated consumption values for lime are illustrated in Figure 5.

According to Figure 5, the total lime consumption for each pre-treatment reactor in this study is presented in kg/ton. The graph shows lime consumption across different process segments in the Aachen reactor: Baseline at 2.95, Pre-ox 1 at 3.15, pre-ox 2 at 3.02, pre-ox 3 at 3.47, and AAL at 3.47 kg/ton. Notably, lime consumption in both pre-ox 3 and AAL segments remained consistent at 3.47 kg/ton. Additionally, lime consumption for the Filblast reactor is shown in the graph as 1.71 kg/ton.

The chart reveals that the Aachen reactor registered the highest lime consumption at 3.47 kg/ton, while the Filblast reactor recorded 1.71 kg/ton. Thus, the difference in lime consumption between the Aachen and Filblast reactors is 1.76 kg/ton, indicating that the experimental consumption was higher in the Aachen reactor by 1.76 kg/ton compared to the Filblast reactor.

Sodium Cyanide (NaCN) Consumption Comparison

During the pre-treatment leaching tests using the Aachen reactor and Filblast reactor, along with their respective subsequent processes, BRT and ALT, sodium cyanide (NaCN) was added. NaCN acts as the leaching reagent, including in the pre-treatment leaching stages performed in this experiment. The cyanide used in the process is laboratory-grade sodium cyanide (NaCN), commonly referred to as technical NaCN, a solid compound.

NaCN consumption data from each reactor and its subsequent process was collected by accumulating the amount of NaCN used in each stage. For the Aachen reactor, NaCN consumption was accumulated at the AAL stage, with further additions for the BRT stage. Similarly, NaCN accumulation in the Filblast reactor was calculated during the reactor process and then added to the subsequent ALT stage. The formula for total NaCN consumption across the pre-treatment processes in each reactor is shown in Table 2.

According to the obtained consumption calculations, the cumulative NaCN usage in the pre-treatment process for the Aachen reactor and its subsequent BRT stage was determined. Similarly, lime consumption for the Filblast reactor was accumulated with the ALT stage. The cumulative lime consumption data is shown in Figure 6.

From Figure 6, the total NaCN consumption for each pre-treatment reactor is presented in units of kg/ton. The chart indicates that NaCN usage in the Aachen reactor at each process stage was 0.65 for the baseline, 0.63 for pre-ox 1, 0.64 for pre-ox 2, 0.60 for pre-ox 3, and 0.55 for the Aachen Assisted Leaching (AAL) stage. The chart also shows NaCN consumption in the Filblast reactor at 0.80 kg/ton.

The data illustrates that the highest NaCN consumption occurred in the Aachen reactor at 0.65 kg/ton, compared to 0.80 kg/ton in the Filblast reactor. The difference in NaCN consumption between the Aachen and Filblast reactors was 0.15 kg/ton. This difference suggests that, in this experiment, the Filblast reactor exhibited higher NaCN consumption by 0.15 kg/ton compared to the Aachen reactor.

6. CONCLUSION

Based on the research results, the following conclusions were reached:

1. In each pre-treatment leaching reactor, the extraction percentages of gold (Au) achieved were 54.30% for the Aachen reactor and 52.19% for the Filblast reactor. For silver (Ag), the extraction percentages were 63.40% in the Aachen reactor and 68.10% in the Filblast reactor. For copper (Cu), the extraction percentages reached 54.40% in the Aachen reactor and 49% in the Filblast reactor.
2. Lime consumption in the Aachen reactor was highest at 3.47 kg/t, observed in PreOx stage 3 and AAL, while in the Filblast reactor it reached 1.71 kg/t. Meanwhile, NaCN consumption in the Aachen reactor was highest at 0.64 kg/t in PreOx stage 2, compared to 0.80 kg/t in the Filblast reactor.

LIMITATION

In this study, several differences in parameters were observed compared to conventional settings. These parameter variations were determined by the specific requirements established by the manufacturers of the respective reactors. For instance, the NaCN concentration for the Aachen reactor was set at 500 ppm, while for the Filblast reactor, it was 1000 ppm. Additionally, the subsequent processes differed, with a bottle roll test (BRT) applied for the Aachen reactor and an agitation leach test (ALT) for the Filblast reactor.

Due to these differences, this study did not aim to compare the % recovery of Au, Ag, and Cu or reagent consumption (such as lime and cyanide) across reactors. Instead, the focus was on assessing the contributions of each reactor relative to the initial sample conditions. Moreover, reagent consumption for each reactor was also evaluated for comparison.

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