Malaysian Journal of Chemistry, 2025, Vol. 27(2), 1-9

Sandioss as an Eco-Friendly Leaching Agent for Refractory Gold Ore Extraction

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This study investigated the extraction of gold from a raw sample sourced from Gua Musang, Kelantan using an eco-friendly leaching agent, Sandioss, as a cyanide substitute. The research focused on the impact of various factors, including Sandioss dosage, leaching time, liquid-solid ratio, pH, and particle size on Au recovery. Results demonstrate that under optimal conditions, specifically Sandioss dosage of 900 ppm, solid-liquid ratio of 30%, pH of 12, particle size of less than 75 µm, and leaching time of 72 hours, the gold concentration increased significantly from 3.112 ppm to 9.716 ppm. Sandioss, a novel eco-friendly gold leaching agent, offers numerous advantages over traditional methods like cyanide leaching, including environmental sustainability, versatility, cost-effectiveness, and safety. For further application, Sandioss can be used to recover Au from electronic waste.

Keywords: Gold; cyanide; Sandioss; leaching agent; pH

Received: July 2024; Accepted: January 2025

Refractory gold (Au) ore can be defined as an Au ore of a low-yield Au recovery of around less than 80% after the ore is normally ground and extracted by cyanidation [1]. It can be characterised by low Au recoveries and high reagent consumption when exposed to direct cyanidation leaching [2]. The ore is challenging to process for three main reasons: first, Au-robbing occurs when dissolved Au is adsorbed by carbonaceous compounds and clay particles during the cyanide (CN) leaching process. Second, even with fine grinding, the finely ground Au particles are embedded in quartz and other minerals, making it impossible for them to come into contact with the reagent. Thirdly, gangue minerals that consume reagents are closely related to carbonaceous elements [3-6]. Refractory Au ores can be classified based on their degree of refractoriness. Free milling ores exhibit the highest recovery rates, with over 95% of Au recoverable. Mildly refractory ores allow recovery rates between 80% and 95%. Moderately refractory ores can be classified with Au recovery rates ranging from 50% to 80%. Finally, highly refractory ores are the most difficult to process, yielding less than 50% recovery of Au [7, 8]. Refractory Au ores can be classified into five categories based on gangue mineral association: physically locked Au, chemically locked Au, reactive gangue minerals, adsorption of Au, and passivation of Au [7, 9, 10].

Over 83% of Au produced globally is extracted via cyanidation due to its simple operation, low cost, and high leaching rate. Nevertheless, CN shows significant biological toxicity and limited leaching effectiveness in refractory Au ores (bearing carbon (C) and sulphur (S)) [11,12, 13]. Yet CN continues to be the standard ligand for Au extraction. Compared to other ligands that are capable of extracting Au, such as halides, thiosulfate ($Na_2S_2O_3$), thiourea ($SC(NH)_2$), and thiocyanate (KSCN), CN has various advantages, including low cost, great effectiveness for Au dissolution, and selectivity for Au over other metals [7, 14, 15]. Due to its relative affordability, high leaching efficiency, and relative selectivity for Au over base metals, cyanidation has been the predominant method for extracting Au from ores for over 130 years in the mining industry [16]. Nonetheless, the amount of Au, and silver, ores that are refractory to cyanidation is increasing, including carbonaceous, telluriferous, pyritic, arsenic, manganiferous, and cupriferous ores [17]. These ores will increase CN consumption, decrease Au recovery, increase process costs overall, and increase hazardous cyano-complex discharge into tailings dams.

Increased environmental pressure to ban or limit the use of CN in plants worldwide is also a prime motivator for research into alternatives to CN. Some of these alternatives not only offer a safer and more environmentally sound extraction method but, for some ores, the use of these lixiviants can also increase the recovery of Au [18]. Several studies have been conducted to find leaching reagents that can replace CN, falling into

CI, $SC(NH)_2$, $Na_2S_2O_3$ [19], and Sandioss. Leaching using Sandioss offers high reaction selectivity during the process, reduced environmental risks, low corrosiveness, and low price, as well as an efficient dissolution medium for refractory Au ores [20, 21].

Using Sandioss, an environmentally friendly Au leaching agent, you can extract Au, and silver, from ores, as well as from oxidation, semi-oxidation, primary, sulphide, high pressure, biological and arsenic-containing original ores, amalgam tailings, CN tailings, sulphuric acid (H_2SO_4) residue, and electronic circuit boards. It is a common chemical that is safe to store, doesn't burn or explode, has no oxidant or radiation risk, and protects the environment [22].

Sandioss is a low-toxicity chemical that is environmentally friendly and produces no pollution, posing no harm to wildlife. It is classified as a common chemical, which does not require special approval for handling. Furthermore, it does not generate harmful gases, and operators can work safely with basic protective gears, such as dust proof clothing, dust masks, and gloves. The tail water resulting from its use can be directly discharged due to its microtoxicity and ability to self-degrade, and if handled properly, it poses no danger. Tailings are classified as solid waste and do not produce harmful gases upon degradation, with a carbon adsorption rate exceeding 99% and a zinc dust replacement rate also above 99%. Additionally, the leaching rate is 99.67%, contributing to a low total cost [22].

In contrast, NaCN is highly toxic, non-environmentally friendly, and causes significant ecological and groundwater pollution. It is dangerous to wildlife, and is classified as a hazardous chemical that requires special approval for handling. The use of NaCN generates hydrogen cyanide gas, necessitating the use of chemical suits, gas masks, and double gloves for operators. Its highly toxic tail water cannot be discharged, and improper handling can result in fatal consequences. Tailings of NaCN are considered hazardous waste, and their degradation releases poisonous gases. The carbon adsorption and zinc dust replacement rates, while above 99%, do not mitigate the overall high total cost, along with a slightly lower leaching rate of 99.64% [22].

This study aimed to investigate and understand the role of Sandioss as an alternative leaching agent in replacing CN in the Au leaching process.

EXPERIMENTAL

Chemicals and Materials

Sandioss, containing sodium oxide (Na_2O), iron carbide, sulfur, and ammonium root [23], was applied as a leaching agent to replace sodium cyanide (NaCN). Sandioss was obtained from Shanghai Sandioss New Material Co. Ltd., China [14]. The raw Au ore sample was collected from Gua Musang, Kelantan, Malaysia. Figure 1 shows a diagram of how Au is physically bound inside pyrite (FeS_2) [7, 24].

Characterisation Methods

Since the aim of this study was to evaluate the effects of selected parameters on the Sandioss process of Au, Au grade and recovery, consumption of Sandioss during the leaching process, solids content, and time taken to leach Au were considered the main results. Other operating parameters, such as temperature, dissolved oxygen concentration, and stirring speed, were maintained constant.

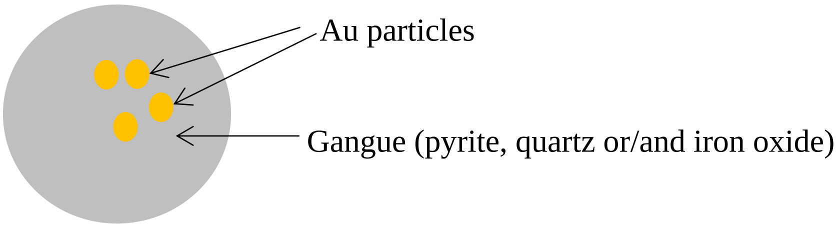

Figure 1. Au is physically bound inside pyrite, quartz or/and iron oxide.

Table 1. The chemical composition of Au ore sample from Gua Musang, Kelantan by XRF.

Composition	Percentage (%)
SiO_2	83.75
Al_2O_3	10.55
Fe_2O_3	3.04
K_2O	2.10
MgO	0.33
TiO_2	0.22
Rb_2O	0.01

Sample Preparation

The samples were prepared in two particle sizes, less than 150 µm and 75 µm, after going through the laboratory comminution process; which involves reducing the size of particles to finer sizes, via crushing and grinding, and is crucial for various analytical and experimental purposes. The representative sample contained 3.112 ppm Au (the value was determined by AAS), and the ore elemental composition using X-ray fluorescence (XRF) is shown in Table 1.

Instrumentation

X-ray Fluorescence (XRF) (XRF – 1700, Shimadzu, Japan) was used to determine the chemical composition in the Au ore sample. A pH meter (SevenEasy pH, Mettler-Toledo, Switzerland) was used to measure the pH value of Sandioss before and after leaching process. An atomic absorption spectrometer (AAS) (AA-6800F, Shimadzu, Japan) and inductively coupled plasma-optical emission spectrometer (ICP-OES) (Optima 5300 DV, Perkin Elmer, USA) were used to analyse Au dissolution.

Gold Leaching Experiments

The Sandioss experiments were carried out in a glass beaker at ambient temperature under different conditions, including pH of 12, solids content of 30%, Sandioss concentration of 800 – 1000 ppm, particle size less than 150 µm and 75 µm, and leaching time of 12–72 h. For each test, a 300 g representative sample was selected. First, the sample solution was prepared in the glass beaker and the pH was adjusted using hydrated lime ($Ca(OH)_2$) to the targeted value. Then, Sandioss was added to the solution and mixed using an overhead stirrer. Each test was carried out at different concentrations of Sandioss. After each experiment, the sample was filtered to collect the filtrate and residue, and analysis for Au dissolution was carried out using an atomic absorption spectrometer (AAS) and inductively coupled plasma-optical emission spectrometer (ICP-OES). Figure 2 illustrates the Au leaching process using Sandioss as a leaching agent. For the preparation of 800 ppm of Sandioss, 3 g of Sandioss was added into a 1 L beaker that contained 600 mL of distilled water:

$$\begin{aligned}\%\ \text{Sandioss} &= \left(\frac{3\text{g}}{600\text{mL}}\right) \text{X}\ 100\% \\ &= 0.5\% \\ \therefore 0.5\% &= 0.5\ \text{X}\ 10000\ \text{ppm} \\ &= 5000\ \text{ppm}\end{aligned}$$

For preparation of 800 ppm of Sandioss:

$$\begin{aligned}\text{Weight of Sandioss} &= 3\text{g X} \left(\frac{800\text{ppm}}{5000\text{ppm}}\right) \\ &= 0.48\text{g} \\ \%\ \text{Sandioss} &= \left(\frac{0.48\text{g}}{600\text{mL}}\right) \text{X}\ 100\% \\ &= 0.08\% \\ \therefore 0.08\% &= 0.08\ \text{X}\ 10000\ \text{ppm} \\ &= 800\ \text{ppm}\end{aligned}$$

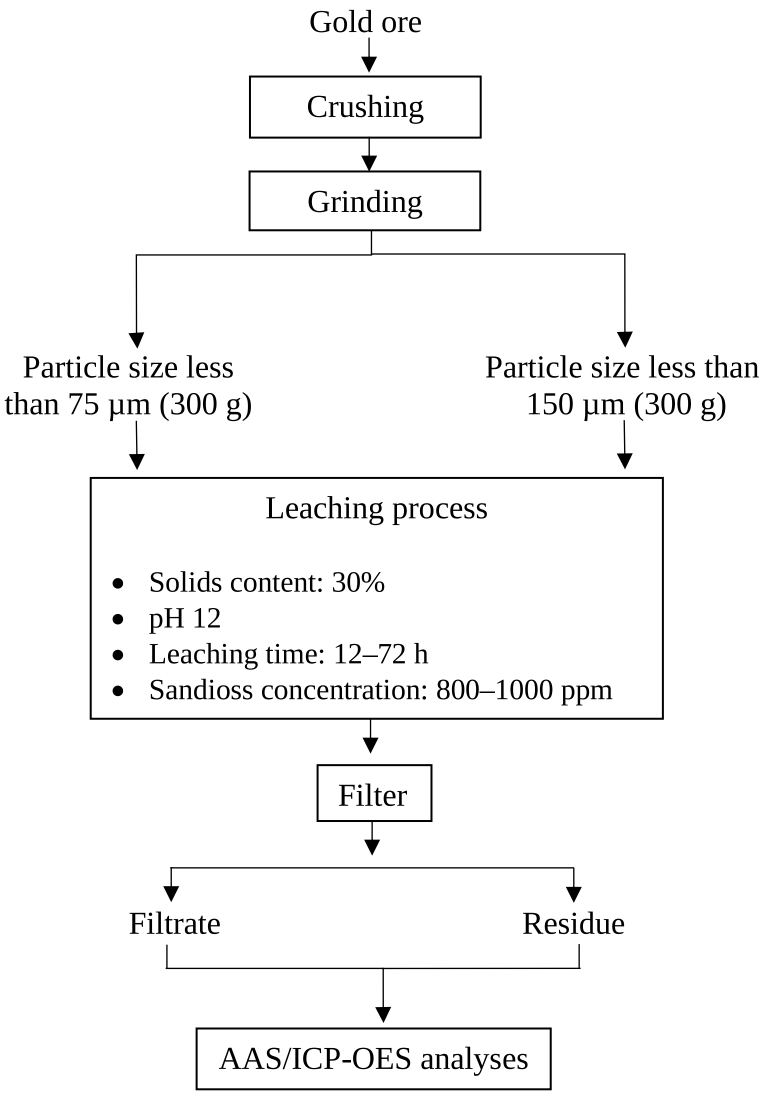

Figure 2. Gold leaching process using Sandioss as a leaching agent.

Gold Assay Using Atomic Absorption Spectrometer

Ten grams of each sample were dissolved in aqua regia after heating at 650°C. In AAS, the sample is aspirated into an acetylene flame. A beam of light at a wavelength matching that of Au is then passed through the flame. The Au in the sample absorbs light proportionately, depending on the concentration of the element in the solution. The absorption is compared to standard solutions to determine the Au concentration in the sample. The operational parameters used in this AAS assay were: wavelength = 267.6 nm, slit width = 0.2, lamp current = 5 mA, background correction (BGC) = D2, and flame type = air-acetylene.

Gold Assay Using Inductively Coupled Plasma Optical Emission Spectrometer

ICP-OES is another alternative method used to analyse the concentration of Au. It offers the advantages of rapid determination of Au and the analysis of several samples. The results for the Au analysis from the present method are in good agreement with fire assay results when the Au concentration is high (above 0.7 ppm). The ICP-OES measurements were performed using the Au emission line at 267.595 nm. One gram of Au ore was digested in 15 mL of nitric acid (HNO_3), silica was removed by adding hydrofluoric acid (HF), and Au was subsequently taken into solution by aqua regia. Aqua regia is a hydrochloric acid (HCl) and HNO_3 mixture with a ratio of 3:1 [25,26].

RESULTS AND DISCUSSION

Characterisation of Optimisation and Environmental Effects

Effects on Sandioss Consumption with Leaching Time

Figures 3 and 4 show the relationship between Sandioss concentration and leaching time for the Au ore that passed through 75 µm and 150 µm sieve sizes, respectively. It can be seen from both graphs that

Sandioss consumption decreased significantly with increasing leaching time. In the early stages of the leaching process (0 – 20 hours), the reaction between Sandioss, as a leaching agent, and the Au particles was typically faster. This is when the maximum consumption of Sandioss occurred, as it dissolves the Au and potentially interacts with other minerals (such as sulphides) in the ore. During this period, Sandioss was actively breaking down the Au and other minerals in the ore. The consumption of Sandioss was relatively high. As the leaching progressed, particularly after the initial reaction phase, the amount of available Au and reactive sites in the ore decreased. The reaction became slow and the consumption of Sandioss decreased because fewer available Au particles or most of the Au had been recovered at the early stage of the leaching process. In Figure 4, it is shown that the best Sandioss consumption for Au leaching for the ore particle size below 150 µm was at the Sandioss concentration of 900 ppm. Less consumption of Sandioss for Au leaching is better because there will be less residual chemical waste to deal with at the end of the leaching process.

Effects of Sandioss Concentration and Samples' Particle Size on Gold Dissolution

Figures 5 and 6 show the effect of leaching time and Sandioss consumption in increasing/decreasing concentration of Au (filtrate/residue) for samples' particle size less than 75 µm and 150 µm, respectively.

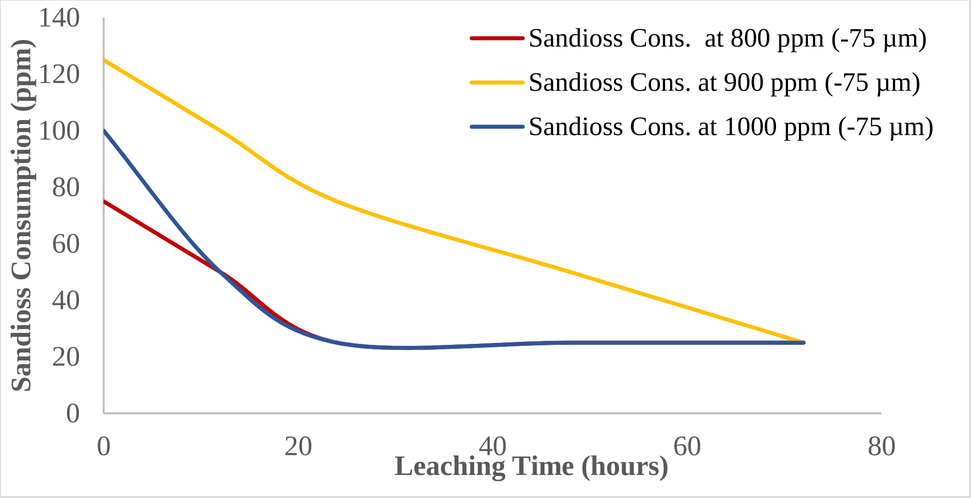

Figure 3: The relationship between Sandioss concentration and leaching time for the sample that passed through 75 µm sieve size (-75 µm).

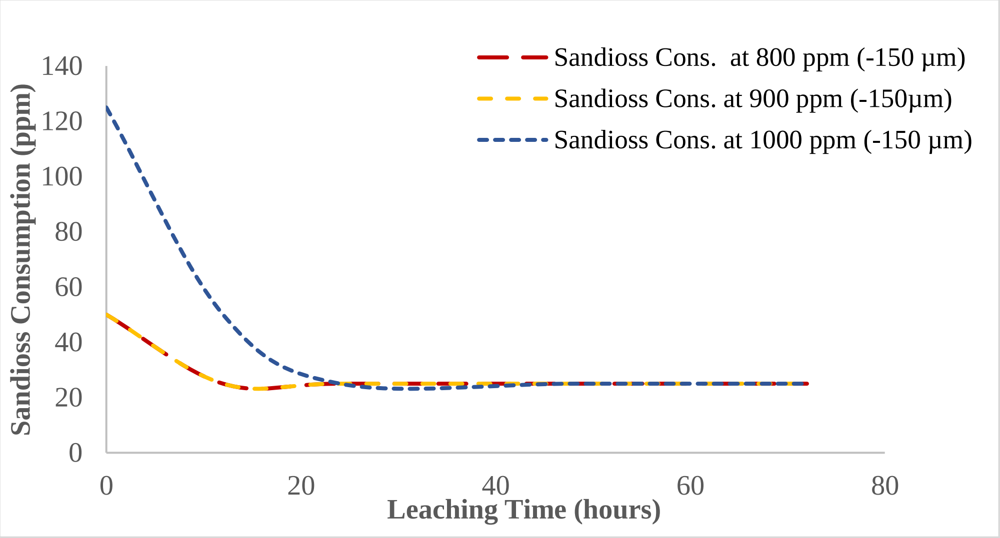

Figure 4. The relationship between Sandioss concentration and leaching time for the sample that passed through 150 µm sieve size (-150 µm).

The graphs show that samples' particle size influences the recovery of refractory Au ore in this study. The finer the size, the more Au concentrations are produced. In this study, the size of less than 75 µm produced a significantly higher value for Au concentration than the feed sample of the size less than 150 µm. The results indicate that the samples' particle size is a crucial factor influencing the efficiency of the Sandioss reaction in Au leaching. Particles smaller than 75 µm are more efficient at leaching Au from the ore than those smaller than 150 µm because smaller particles have a larger surface area per unit mass, which exposes more Au-bearing minerals to the Sandioss reagent.

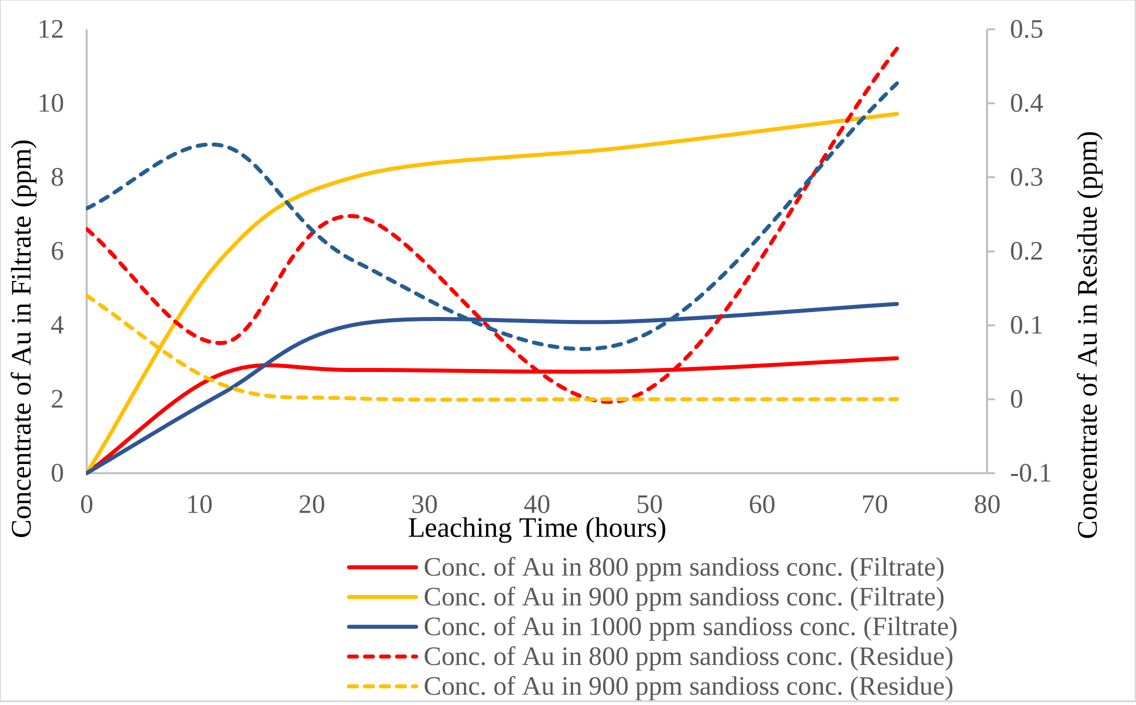

Figure 5. Effects of leaching time and Sandioss consumption in increasing/decreasing concentration of Au (filtrate/residue) for the sample of particle size less than 75 µm.

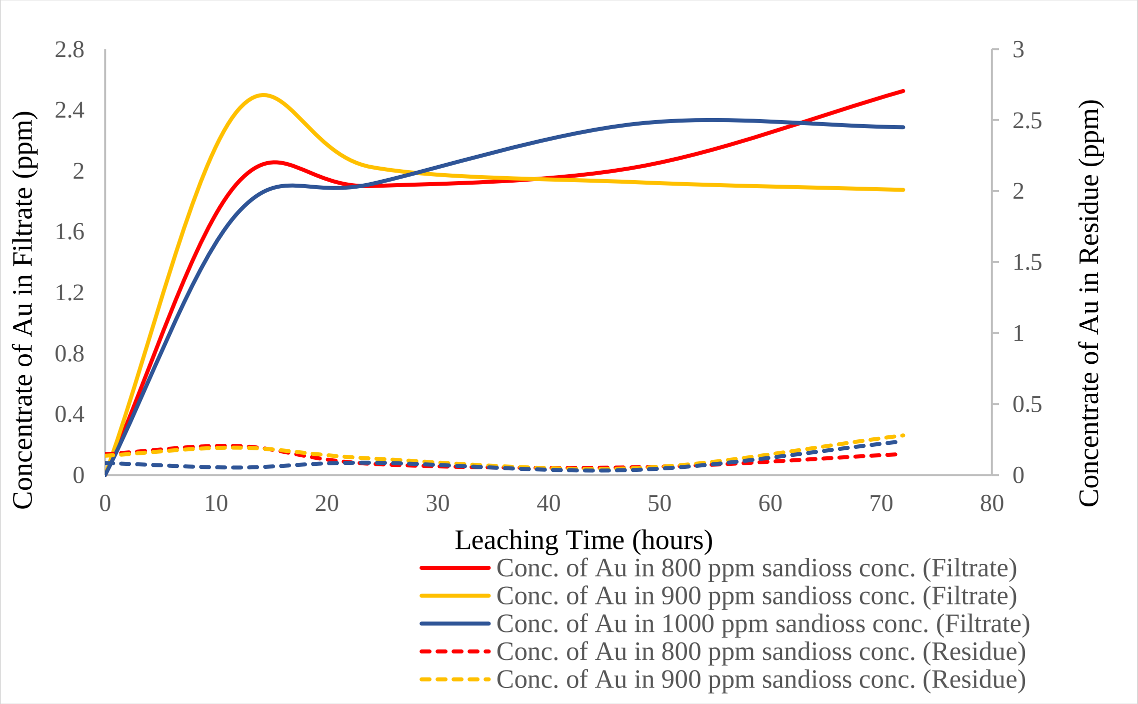

Figure 6. Effects of leaching time and Sandioss consumption in increasing/decreasing concentration of Au (filtrate/residue) for the sample of particle size less than 150 µm.

Effects of Leaching Time on Gold Grade

Figures 7 and 8 show the relationship between leaching time and Au concentration for samples' particle size less than 75 µm and 150 µm, respectively. It can be seen that leaching time has a strong influence on the grade of Au. The highest Au grade that could be extracted was at 48 h and 72 h, with the feed particle size of the sample being less than 75 µm. The concentration of Au that dissolved at 48 h and 72 h was triple that of the Au in the head assay. It increased from 3.112 ppm to 8.810 ppm at 48 hours of leaching time and 9.716 ppm at 72 hours of leaching time, but for the feed sample with the particle size of less than 150 µm, the Au grade achieved was lower than the grade of Au in the head assay. It can be concluded from Figures 7 and 8 that the significant particle size for Au leaching using Sandioss is less than 75 µm. Based on the data presented, the optimal particle size for efficient Au extraction using Sandioss is less than 75 µm. Smaller particles provide greater surface area for the leaching agent to interact with Au-bearing minerals, leading to enhanced Au dissolution and higher recovery rates.

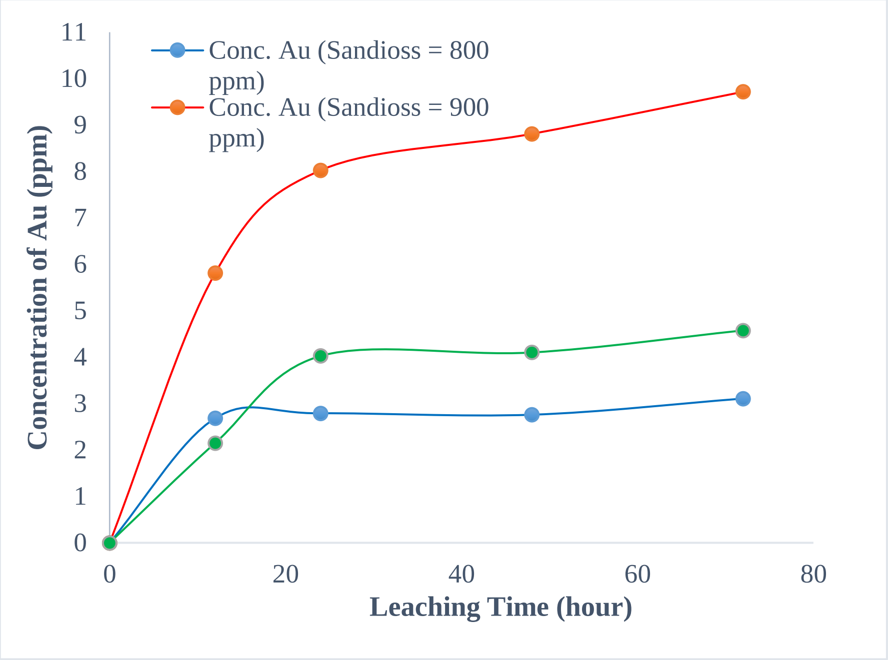

Figure 7. The relationship between leaching time and Au concentration for the sample of particle size less than 75 µm.

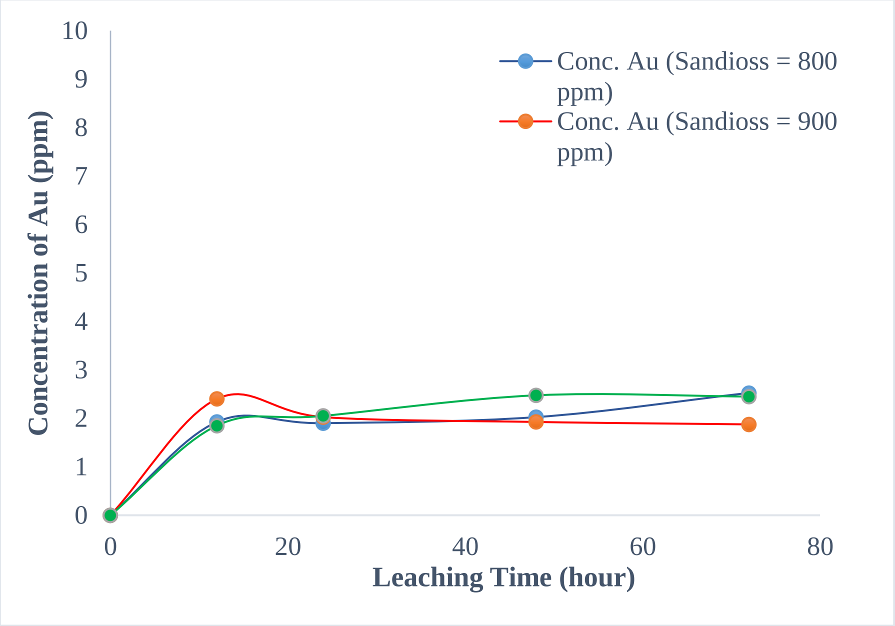

Figure 8. The relationship between leaching time and Au concentration for the sample of particle size less than 150 µm.

Effects of Sandioss Usage on the Environment

Observation and handling of the reagent before, during, and after the experiment show that there is no dangerous impact on the people handling Sandioss or the surrounding area. No poisonous or harmful gases were produced during the experiment. The tailing can be directly discharged because it is a self-degrading reagent and not dangerous. The properties of Sandioss have proven that the reagent is environmentally friendly and can be used as an alternative reagent to replace CN for refractory Au ore leaching. The present study has shown that particle size, Sandioss concentration, and pH are important variables influencing the attainment of a high concentration of Au, compared to previous studies that focused on leaching time, Sandioss concentration, and pH [21]. Based on the particle size variable, the present study has demonstrated that a smaller particle size is more effective in extracting Au through the leaching process than a larger, coarse particle size of the sample.

CONCLUSION

The efficacy of Sandioss as a refractory Au leaching reagent has been investigated. In terms of the leaching process, Sandioss is considered an effective leaching reagent because it could increase the concentration of Au from 3.112 ppm to 9.716 ppm after 72 hours of leaching time of the refractory Au ore. In this study, the samples' particle size also has a contribution to Au dissolution. The significant leaching size of refractory Au ore in this study was less than 75 µm because more Au was liberated from its associated minerals at this condition. From all the experiments conducted, it has been proven that Sandioss has the potential to be a lixiviant for Au leaching. Due to its non-toxic nature, it can be used as a leaching reagent to replace NaCN in refractory Au ore leaching. Handling of the reagent is easy because no poisonous or harmful gases were produced during the experiments. The tailing can be directly discharged because it is a self-degrading reagent and not dangerous.

ACKNOWLEDGEMENT

The authors would like to thank and are also pleased to acknowledge the support of the Senior Director of the Mineral Research Centre, Department of Mineral and Geoscience Malaysia, Dr Nazwin binti Ahmad, and fellow staff from the Branch of Mineral Processing Technology and the Branch of Mining and Rehabilitation Mine for their valuable help and assistance in conducting the experiments, especially Siti Nur Ain binti Mat Din and Mohd Zaid bin MD Sharif.

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