Original Article

Review of gold cyanide leaching and the main factors affecting gold dissolution rate

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Abstract

This paper reviews the cyanide leaching technology and the influential parameters affecting the cyanidation process. In general, the factors influencing the degree of cyanide leaching of gold include particle size, NaCN concentration, the level of dissolved oxygen, pH, pulp density, and leaching time. Each of these parameters plays a significant role in gold cyanidation, and should be optimized respectively by conducting laboratory testing prior to production application.

Keywords: Gold ore; cyanide leaching; gold dissolution; particle size; cyanide concentration; dissolve oxygen; pulp density

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1 Introduction

As a key mineral resource which can be separated from gold ores, gold has been the focus of mining activity in the areas of exploration and metallurgy[1]. The total gold supply in 2022 is estimated to be 4,754 tons, which includes approximately 3,612 tons from mine production with the remainder primarily produced from waste recycling[2]. Mine production was, is and will continue to be the key source of gold production. The world's largest gold producing countries are China, Australia, Russia, and Canada[3]. Over the past decades, the demand for gold has steadily increased, and the worldwide annual gold demand has surged to an 11-year high in 2022 and jumped 18% to 4,741 tons[2], which is just below the total supply of gold in the year.

Amongst the world's mineral resources, gold is unique. This is not only because it is among the first metal minerals developed and applied by mankind, but also because it has various mineral processing technologies. This original review article is a brief review of cyanidation, the primary and most widely used mineral processing technique for gold ores.

2 Summary of cyanidation process

As a high value and recoverable noble metal, gold (Au) is widely distributed in low concentrations in a number of geological environments. Gold mostly occurs as pure native gold, gold-silver electrum, or chemically combined with tellurium, selenium, and bismuth. Sylvanite and calaverite are gold-bearing minerals. Gold is usual found embedded in quartz veins or associated with sulphide minerals, principally arsenoprite and pyrite, in sulphide mineralization.

Conventionally, gold is selectively dissolved from its ore using an aqueous sodium cyanide solution in the presence of oxygen to solubilize the gold. The dissolved gold is then precipitated from the pregnant leach solution (PLS) by zinc dust or extracted from PLS by adsorption on activated carbon or resins. This process is called cyanide leaching, also referred to "Cyanidation". Cyanidation has been both the primary technology and a well-adopted industry standard method for gold processing since it was first put forward by John Stewart MacArthur in the 1880s[4], due to its high efficiency, simplicity, robustness, and relatively low cost. This cost-effective, well-proven gold extraction method provides maximum recovery for many free-milling gold ores, including low grade and some refractory ores. More than 75% of the gold produced worldwide is extracted by cyanide leaching of gold ores[5].

Undoubtedly, cyanide leaching is still the most important and widespread of the various hydrometallurgical technologies used in the extraction of gold from primary ores. In fact, cyanidation remains the main choice today for the recovery of gold from low-grade and finely disseminated gold ores in both technological and economical respects.

3 Factors affecting cyanidation process

Gold cyanidation follows an electrochemical-chemical reaction between cyanide and gold according to the following equation[6]:

$$2Au + 4NaCN + \frac{1}{2}O_2 + H_2O + 2OH^- \rightarrow 2Au(CN)^{2-} + 4NaOH$$

During cyanide leaching, in addition to sodium cyanide and oxygen as listed in the equation, many other factors also play important roles in gold dissolution. The influential parameters affecting the cyanidation process include the availability of oxygen at the solid–liquid interface, the pH of the leach slurry, pulp density, the presence of ions other than CN^- in solution, the cyanide concentration, the particle size of the ore, the leach temperature, the surface area of gold exposed, the mineralogical characteristics of the ore, the degree of agitation and leaching time, etc.

3.1 Oxygen

The cyanidation hydrometallurgy technique consists of an electrochemical process that oxidizes gold and reduces oxygen with cyanide solutions. As seen in the gold and cyanide reaction equation, oxygen is the one of the two main components of the cyanidation process, and is essential in gold cyanidation. It not only oxidizes gold itself to an ion that can form the water-soluble complex salt $Au(CN)^{2-}$ in the presence of cyanide, but also assists with oxidation of other metal ions, such as those of iron and copper. Thus, the concentration of oxygen is one of the most important factors in the gold cyanidation process.
The source of oxygen can be air, oxygen, hydrogen peroxide (H_2O_2) or other oxidizing agents such as *LeachAid*®, $KMnO_4$ and Cl_2. Currently most cyanidation plants utilize aeration to provide the required dissolved oxygen ($d.O_2$) in pulp. The $d.O_2$ concentration can be boosted by high pressure aeration, oxygen injection, or the addition of oxygen-rich solutions. The use of oxygen compounds instead of air as an oxidant increases the leach rate and decreases cyanide consumption, as it provides more oxygen (higher $d.O_2$) in leach slurry.
Generally, increasing the concentration of $d.O_2$ in leach solution improves the gold cyanidation process, thus increasing gold dissolution rate.

3.2 Cyanide concentration

As the other main component of the cyanidation process, the concentration of cyanide is essential.
As noted in the chemical reaction between gold and cyanide, in the cyanidation process gold reacts with cyanogen (CN^-) under the action of oxygen and forms a water-soluble cyanogenic gold complex $Au(CN)^{2-}$. Therefore, the cyanide concentration is one of the most decisive factors in the gold cyanidation process.
The NaCN concentration in the cyanide solution typically ranges from 100 ppm to 500 ppm cyanide. Cyanide leaching of gold requires a certain amount of free cyanide in solution. In general, higher cyanide concentration benefits gold dissolution; the higher the cyanide concentration, the faster the gold dissolution.

3.3 pH

The pH affects the cyanide leaching process in the following ways[7]:

- to prevent loss of cyanide, and the formation and release of the toxic and fatal hydrogen cyanide (HCN);
- to neutralize acidic compounds in mill water prior to adding to the mill;
- to neutralize the acidic components in the ore or resulted from decomposition of various minerals in the ore during grinding;
- to assist with settling of fine particles in the ore and/or resulted from milling of the ore;
- to improve gold dissolution when treating ores containing telluride minerals, ruby silver, which decompose more readily at higher alkalinities.

Alkalis such as hydrated lime (calcium hydroxide $Ca(OH)_2$) or sodium hydroxide (NaOH) are generally used to adjust and maintain the leach slurry pH to >10 during the cyanide leaching process. Research found that, when using hydrated lime, the gold dissolution rate decreases rapidly when the pH is close to 11.0 and is negligible once pH reaches 12.2. However, the effect of sodium hydroxide is much less[7]. The gold dissolution rate does not slow until pH 12.5 when sodium hydroxide is used.

3.4 Pulp density

Pulp density also refers to the solid-liquid ratio of pulp, which directly affects the diffusion rate of cyanide and oxygen in the pulp.
The pulp density in leaching of normal gold ore is usually controlled at 40- to 55 wt.%. Higher pulp density results in lower pulp flow and lower gold leaching rate; lower pulp density benefits gold dissolution rate but the requirements on equipment volume increases along with the cyanide reagent. The maximum gold dissolution increases with a decrease in pulp density.

3.5 Ions in solution other than CN^-

Irons such as copper can react with cyanide and form different complexes which deplete the necessary amount of free cyanide required for gold dissolution, thereby decreasing gold leaching. Thus, a high concentration of copper can interfere with gold dissolution and lead to soluble gold losses, the production of weak acid dissociable (WAD) cyanide, as well as a number of operational challenges in the downstream CIP/CIL circuits with respect to competitive adsorption, and subsequent difficulties associated with elution, electrowinning and smelting[8]. Furthermore, as copper minerals are significant cyanide consumers, the presence of copper ion leads to higher cyanide consumption during the leaching process and higher operational costs[9].

3.6 Particle size

Almost all gold ores require grinding to liberate and unlock the gold particles in the host matrix so the surface of gold minerals particles can be exposed prior to cyanide leaching for gold extraction.
The particle size of ore positively affects the surface area of gold exposed to cyanide solution. Reduction of the particle size of the ore creates more surface area of exposed gold and increases the contact surface area between the ore and cyanide solution, which ultimately increase the gold dissolution rate. Generally, finer particle sizes result in better gold dissolution. For gold ores requiring oxidation pre-treatment, the gold contained in the fine-size fractions usually shows a good dissolution without pretreatment[5].
Depending on mineral liberation, the particle size of ore in most leaching plants can vary from P_{80} 75 µm to 220 µm.

3.7 Temperature

Gold dissolution rate can be advanced with an increase in temperature during cyanidation, but the amount of dissolved oxygen will significantly decrease as temperature increases and becomes zero once the temperature reaches 100 ^{o}C, at which point no more leaching occurs[10].
In general, the cyanidation process does not require heating, and is maintained at 15-30 ^{o}C or carried out at the atmospheric temperature of the plant.

3.8 Degree of agitation

During cyanide leaching of gold ores, the pulp needs to be agitated or mixed to increase the solubility of oxygen and gold-cyanide reaction.
Increasing the agitation speed promotes the diffusion rate of gold-bearing mineral particles in the leaching solution, hence increasing the leaching efficiency.

3.9 Leaching time

The gold cyanide leaching process is relatively slow, and usually requires more than 24 hours to complete. In general, leaching time has a positive effect on gold dissolution, and the gold dissolution rate improves with the extension of leaching time however, the gold leach speed decreases correspondingly and the final gold dissolution rate trends to a limit point, at which point increasing leaching time no longer improves final gold leaching rate.
Leaching time varies significantly from ore to ore. For low-grade oxide ores, gold leaching can complete within 24-30 hours at a target grind size P_{80} 75-150 µm; while for complex ores with sulphide mineralization, it may take 72 hours or even longer to reach the maximum leach rate.

4 Discussion and conclusions

The main advantages of cyanidation are low cost, high selectivity of free cyanide for gold dissolution, and the extremely high stability of the cyanide complex. The most important disadvantages of this process are the toxicity and disposal problems of leaching wastes into the environment unless the necessary precautions are taken. As an alternative process to cyanidation, thiourea, thiosulfate, chlorine, and acid leaching methods have been developed in recent years, but none of these have yet gained industrial application[6]. At least in the near term, cyanidation will continue as the main technique for gold extraction in the mining industry. Understanding the factors affecting cyanide gold dissolution rate is crucial. Although many factors play important roles in cyanide leaching of gold ores, the main ones influencing gold dissolution rate most are particle size, the concentration of dissolved oxygen, NaCN concentration, pH, pulp density, and leaching time. In general, the factors influencing the degree of cyanide leaching are in the order of leaching time > NaCN concentration > particle size > pH > pulp density.

Prior to production application, these leach parameters need to be evaluated and optimized in a laboratory testing facility by bottle roll or column testing to evaluate the ore's amenability to the cyanide leaching process, expected gold recovery, and reagent requirements.

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Author contributions A Shi contributed to the whole research, compilation, interpretation, and writing of the paper. The author prepared and reviewed the manuscript and approved the final version of the manuscript.

Data availability statement The data and information that support the study are based on the author's experience, and part of which are available from the academic publications, which were lucidly and relevantly cited as references.

Declarations The author declares that she has no conflict of interest.

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