AMMONIACAL CYANIDE LEACHING OF COMPLEX GOLD ORE

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SCHOOL OF MATRIALS AND MINERAL
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AMMONIACAL CYANIDE LEACHING OF COMPLEX GOLD ORE

By

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled ‘Ammoniacal Cyanide Leaching of Complex Gold Ore’. I also declare that it has not been previously submitted for the award of any degree and diploma or other similar title of this for any other examining body or University.

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Witness by

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

PELARUTLESAPAN SIANIDA AMMONIA DARI EMAS

ABSTRAK

Sampel bijih emas yang diperoleh dalam kajian ini telah terdedah kepada larut lesap sianidasi ammonia pada kepekatan reagen ammonia (NH_3) dan natrium sianida (NaCN) yang berbeza pada pengekstrakan emas dan kuprum. Pencirian mineral bagi sampel bijih emas telah dijalankan untuk mengenal pasti korelasi mineral, komposisi mineral dan fasa mineral melalui analisis XRD, dan XRF. Kaedah ujian ‘bottle roll’ digunakan untuk mendapatkan maklumat asas tentang kebolehlarutan bijih galas Au tertentu. Kesan primer dan interaksi NH_3 dan NaCN ditunjukkan dalam sistem sianida ammonia menggunakan reka bentuk eksperimen ‘Full Factorial’. Kepekatan NH_3 dan NaCN telah dibuktikan secara statistik sebagai penentu utama yang mempengaruhi pengekstrakan emas. Jumlah emas yang diperoleh daripada teknik ujian kebakaran ialah 2.762 mg/L. Hasil terbesar menggunakan teknik larut lesap ammonia untuk menentukan emas bebas dalam sampel bijih emas ialah 2.625 mg/L menggunakan 3000 ppm sianida, dan 1000 ppm ammonia. Oleh itu, dapat disimpulkan bahawa pelarut larut lesap ammonia boleh meningkatkan pembebasan zarah emas yang tinggi dengan penggunaan sianida dan ammonia yang tinggi.

AMMONIACAL CYANIDE LEACHING OF COMPLEX GOLD ORE

ABSTRACT

The gold ore samples obtained in this study were exposed to ammonia cyanidation leaching at different levels of ammonia (NH_3) and sodium cyanide (NaCN) reagents in gold and copper extractors. Mineral characterization of gold ore samples was carried out to identify mineral correlation, mineral composition, and mineral phase through XRD and XRF analysis. The 'bottle roll' test method is used to obtain basic information about the solubility of certain Au-bearing ores. The primary effects and interactions of NH_3 and NaCN are shown in the ammonia cyanide system using a 'Full Factorial' experimental design. NH_3 and NaCN concentrations have been statistically proven to be the main determinants affecting gold extractability. The amount of gold obtained from the fire test technique is 2.762 mg/L. The largest yield using the ammonia leaching technique to determine free gold in gold ore samples was 2.625 mg/L using 3000 ppm cyanide, and 1000 ppm ammonia. Therefore, it can be concluded that ammonia leaching solvent can increase the release of high gold particles with high consumption of cyanide and ammonia.

CHAPTER 1 CHAPTER 1

INTRODUCTION

1.1 Research Background

Gold cyanidation (also known as the cyanide process or the MacArthur-Forrest method) is a hydrometallurgical methodology for extracting gold from low-grade ore by dissolving the gold to a water-soluble coordination complex. It is the most extensively used leaching technique for gold extraction. It is the gold extraction leaching technique that used the most frequently. A specific ore must be examined in a laboratory to evaluate its cyanidation liability, leaching behaviour and kinetics, and proclivity to consume cyanide. Several methodologies for laboratory testing and assessing the cyanide leaching behaviour of Au-bearing ores have been provided. Bench-scale bottle roll testing, on the other hand, has long been used to get early insight into the leachability of a certain Au-bearing ore. The technique is simple and easy to apply, and it is thought to provide reliable and timely data that will serve as the foundation for future evaluation of a specific ore in terms of a predicted leaching process and scaling-up of leaching methods (Plenge, 2015).

Most primary metal production requires hydrometallurgical processing, which enables some metals, including copper and gold, to be refined from crushed ore or concentrated minerals, to produce a finished metal product. The basic ore slurry can be supplemented with a solution of sodium cyanide or potassium cyanide; however, calcium cyanide is often used since it is more economical.

The most important use of gold is as a bullion, i.e., a reserve for money distributed. gold valued for its use as jewellery, gold plating and in dentistry.

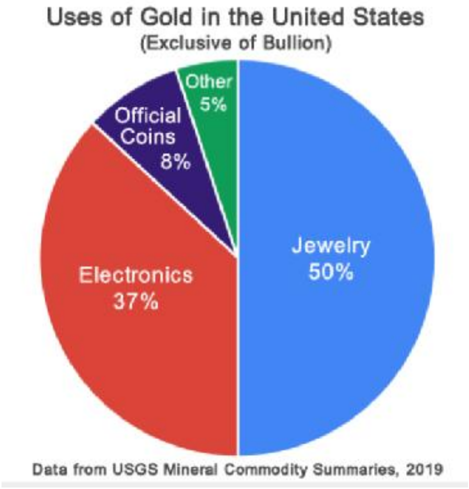

Figure 1-1 Uses of Gold in the United States (Gold Uses in the Modern Economy, 2019)

This pie chart shows how gold used in the United States in 2019, not including gold bullion. The main uses were in jewellery (50%) and electronics (37%). The minting of official coins accounted for 8% of the gold used, and 5% was for other uses. Data from the USGS Mineral Commodity Summaries for 2019 (Gold Uses in the Modern Economy, 2019).

At the mining site, all procedures, including physical and chemical processes, were carried out to extract gold, a highly lucrative mineral. The gold ore samples 'as received'. An appropriate assaying procedure was used to ascertain the total gold content of the samples. The assaying methods used in this study were the fire assay technique. The bottle roll test was also used to calculate the amount of free gold. Finally, gold leaching will be carried out on the gold ore samples.

However, gold is one of the noble metals and as such it is not soluble in water. Cyanide, which stabilizes the gold species in solution, and an oxidant such as oxygen are required to dissolve gold. Reagent interactions have a statistically considerable impact on gold extraction. The addition of ammonia into the solution is recommended for the treatment of gold ores with high copper sulphide content. Conjunction with that, this research will study on the ammonia cyanide leaching with the addition of lead nitrate.

This design of experiment is aimed to increase the extraction of gold and its performance in economically. At the end of this project, the addition of ammonia and lead nitrate in cyanide leaching can be used to treat the ore in high sulphidation epithermal gold silver deposits.

1.2 Problem Statement

Cyanide leaching of gold is a widely used process for evaluating low-grade gold ores. Despite the hazards involved with cyanide, the approach proved to be exceedingly efficient when measures were used. Field-scale gold cyanidation is mostly accomplished by heap and tank leaching techniques. The decision between options is determined by several parameters, including the quality of precious metals in the ore, the amount of the reserve, and so on. The susceptibility of the Au-bearing ore to cyanidation is the most essential feature, regardless of technique. In other words, the extraction of gold from the supplied ore must be justified before considering any leaching process for field scale operation. A particular ore must be tested on a laboratory scale to precisely determine its cyanidation liability, leaching behaviour and kinetics, and inclination to consume cyanide.

Cyanide leaching is indeed not intrinsically a selective methodology since many other metals or minerals are available and conveniently soluble under cyanide leaching prerequisites (Ahmet Deniz Bas, 2015). Most copper minerals are extremely soluble in cyanide solutions, except for chalcopyrite and tetrahedrite, which are rather stable. The appearance of these soluble minerals potentially obstruct cyanide leaching and subsequent gold recovery methods (Bas A D, Assesment of ammoniacal ammonium sulphate leaching as a pretreatment process for copper bearing gold ores, 2012). The detrimental effect of copper is associated with the excessive consumption of cyanide through the formation of highly stable copper cyanide complexes leading to poor gold extractions when sufficient level of cyanide is not provided (Akmirza, 2014).

Prior to tailings disposal, considerable levels of weak acid dissociable (WAD) cyanide must be eliminated. This raises the cost to gold mining businesses to pay both the greater cyanide consumption in the leaching stage and the additional cost for cyanide recovery (E.A. Oraby, 2016). In most situations, cyanide must be removed prior to ultimate tailings disposal, generally by chemical oxidation, which increases the expense of cyanidation. Copper cyanide is a frequent component of precious metal ores that can be treated using cyanide. Laboratory column tests can forecast the copper content in production wastes, although the exact correlation is not always clear. In general, heap leach operators like to keep copper concentrations between 300 and 500 ppm and may experience issues with gold recovery and cyanide consumption if copper concentrations surpass this level (Kappes, 2012)

The stoichiometry by which this reaction occurs is kwon as Elsner (1846) equation as shown below in Equation 1.1.

$4Au + 8NaCN + O_2 + 2\ H_2O \rightarrow 4\ Na\ [AuCN)_2] + 4NaOH$ Equation 1.1

Cyanide has been used to extract gold from gold ore producing ores, and most of the world's gold is recovered with cyanide playing a major part in the precious yellow metal's beneficiation. According to the equation above, the only elements are gold, sodium cyanide, and water.

After cyanidation for any of the alternatives, a considerable part of copper minerals reacts strongly with alkaline cyanides. Gold cannot be recovered by standard cyanidation due to the high copper percentage of this transition ore, which results in excessive cyanide consumption (J.A.M.Romayna, 2001). These high Cu concentrations, which are usually found in cyanide-soluble copper minerals such oxides (cuprite and malachite), sulphides (chalcocite, bornite, and covellite), and native Cu, lead to a rise in cyanide consumption (J.A.M.Romayna, 2001). As a result, treating them conventionally is uneconomical.

When enough cyanide is not delivered, the adverse effect of copper relates to the excessive consumption of cyanide as shown in Equations (1.2)-(1.6) through the creation of very stable copper cyanide complexes, resulting in poor gold extractions. When copper sulphides such as covellite are present, thiocyanate (Equations. (1.4) and (1.6)) and cyanate (Equation. (1.5)) are formed in addition to copper cyanide complexes. (Sceresini B, 1991)

$Cu^{2+} + 2CN^{-} \rightarrow Cu(CN)_2$ Equation 1.2

$Cu_2O + 6CN^{-} + H_2O \rightarrow 2Cu(CN)_3^{2-} + 2OH^{-}$ Equation 1.3

$Cu_2S + 7CN^{-} + 1/2O_2 + H_2O \rightarrow 2Cu(CN)_3^{2-} + 2OH^{-} + CNS^{-}$ Equation 1.4

$2CuO + 7CN^{-} + H_2O \rightarrow 2Cu(CN)_3^{2-} + 2OH^{-} + CNO^{-}$ Equation 1.5

$2CuS + 8CN^{-} + 1/2O_2 + H_2O \rightarrow 2Cu(CN)_3^{2-} + 2OH^{-} + 2CNS^{-}$ Equation 1.6

Sulphide ion (S^{2-}) that is released from sulphide phases including copper sulphides present in the ore can also lead to the passivation of gold surface in addition to its consumption of cyanide and oxygen (Marsen J O, 2006). The sulphidic copper–gold ores are floated, and gold is recovered as a by-product of copper smelting and refining.

However, transition or sulphidic ores gave poor gold recovery and required higher reagent concentrations. Staged addition of NaCN was found to increase the recovery of gold and the dissolution of copper minerals from the ore, but recycling of the copper solution after gold recovery led to a decrease in gold extraction as the copper concentration in solution increased significantly (Montgomery, 2001).

Overall, this research is likely to study the problems faced by gold mine company which are the high consumption of cyanide due to other minerals present in the ore and leading to uneconomic process.

1.3 Objectives

a) To investigate of main and interaction effect of ammonia (NH_3) concentration, sodium cyanide (NaCN) on the extraction of gold and copper.
b) To evaluate the effect of addition of ammonia (NH_3) on cyanide consumption.

1.4 Thesis Outline

This study will focus on methods that have been applied and can be carried out such as fire analysis. Gold extraction from ore is a complex work. The most popular process is cyanide leaching, in which gold is extracted from its ore using cyanide salts in solution.

The link between gold, silver and copper extractions, ammonia consumption, and cyanide consumption will examine in the ammoniacal cyanide leaching performance of a sulphide gold-silver ore. The leaching will conduct 24 hours of leaching. The ammonia–cyanide leach technique, which was initially patented over a century ago, is a one-of-a-kind method of selectively leaching up to 90% Au and 1% Cu from oxidized copper–gold ores using the same 10% NaCN used in traditional cyanidation (B, 2005).

Numerous processes have been investigated in recent years to address the issues caused by copper mineral dissolution during gold extraction. Pre-aeration (before to the introduction of cyanide) of some ores, particularly those that are partly sulfurized, in water at a high pH can leave components like iron and sulphur less reactive to cyanide, making the gold cyanidation process more efficient.

CHAPTER 2

LITERATURE REVIEW

2.1 Gold and Gold Ore Extraction

2.1.1 General Description of Gold

Gold or aurum is a chemical element in the periodic table that has the symbol Au and atomic number 79. These metals exist as lumps or grains in rocks, underground slabs and in alluvial deposits. Gold is heavy precious metals that have higher density which is 19.34 gcm^{-1} at 20 plus has highest ductility and malleability among metals. Pure gold has a bright yellow colour and is considered attractive, and this colour remains without undergoing oxidation of air or water. Generally, gold can be found in hydrothermal deposits or sedimentary placer deposits that commonly associated with silver, copper, and lead nitrate (A. D. Bas 1, 2017).

Since the ancient period, gold has been sought for coinage, jewellery, and other works of art. In 2009, 165,000 tons of gold were extracted for the first time in human history. This amount is about equivalent to 5.3 billion troy ounces or 8.500m3 in terms of volume. New gold is used in the globe in around 50 percent of cases as jewelleries, 40 percent as investment, and ten percent as industrial (Gold Uses in the Modern Economy, 2019).

The most prevalent ore type is gold-copper ores, with gold being the most valuable and copper being a secondary. They are treated with cyanidation. However, recovering the gold and silver found in some copper ores by acid leaching is impractical, preventing the economic advantages from being achieved (Humberto Estay, 2013).

Gold is a transition metal in chemistry. Pure gold, in comparison to other metals, is chemically the most reactive, has acid resistance, but is less efficient against aqua regia acid aqua regia combination, which may dissolve gold (J.A.M.Romayna, 2001).

2.1.2 Gold Extraction

The techniques involved in extracting gold from its ores are known as gold extraction. For processing of ore, involve of comminution, mineral processing, hydrometallurgical, and pyrometallurgical operations. Once the ore has been mined, it can be processed as a whole ore utilizing dump or heap leaching methods. This is characteristic of oxide deposits with a low grade. Prior to heap leaching, the ore is usually crushed and agglomerated. To extract gold values from high-grade ores and ores resistant to cyanide leaching at coarse particle sizes, further processing is required. Grinding, concentration, roasting, and pressure oxidation can all be used as processing procedures before cyanidation.

2.1.2(a) Leaching Process

In extractive metallurgy, leaching is a process in which ore is treated with chemicals to turn the precious metals inside it into soluble salts while the impurities remain insoluble. The materials left behind are known as tailings, and they can be washed off and treated to get pure metal. Leaching is easier to execute than pyrometallurgy, consumes less energy, and is theoretically less damaging because no gaseous pollution occurs. The release of organic and inorganic pollutants or radionuclides from a solid phase into a water phase when influenced by processes such as desorption, complexation, and mineral dissolution is referred to as leaching.

When impacted by processes such as desorption, complexation, and mineral dissolution, the leaching process describes the release of organic and inorganic pollutants or radionuclides from a solid phase into a water phase. The leaching process is a universal process in which water will leach the components of any substance it comes into touch with, whether from the surface or from the inside (based on the porous nature of the material). The ore of a metal can be concentrated with this method by creating a chemical reaction with a reagent, which causes the ore to dissolve while the impurities remain undissolved (What is Leaching Process?, n.d.).

2.2 Factors That Effect Cyanidation Process

2.2.1 Cyanide Concentration

The concentration of sodium cyanide decreased as gold and silver extraction progressed, and autoclave leaching could not be finished adequately in a single step. The extraction of gold and silver increased when the cyanide concentration was increased.

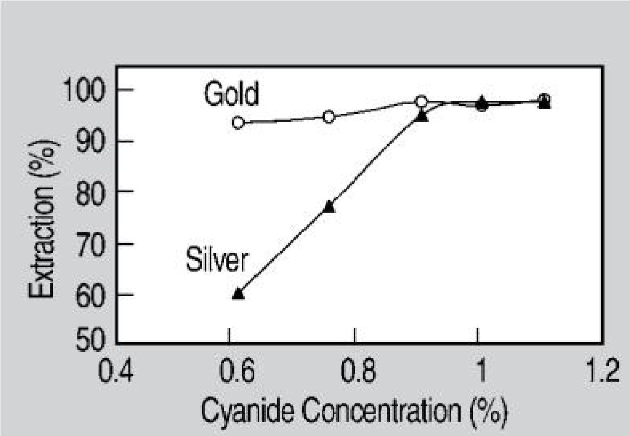

Figure 2-1The effect of cyanide concentration on gold and silver extraction (José R. Parga, 2007).

2.2.2 Ammonia Concentration

The use of an ammonia cyanide mixture can reduce the cyanide consumption. Ammonia can be introduced as a modifying agent in cyanide leaching to minimize copper interference which is allowing substantial reduction in cyanide consumption. The addition of ammonia at a concentration of 3 M NH_3 resulted in nearly full gold extraction (Figure 2.3). The leach rate of pure gold reduced as the ammonia content increased, according to (Ahmet Deniz Bas, 2015)

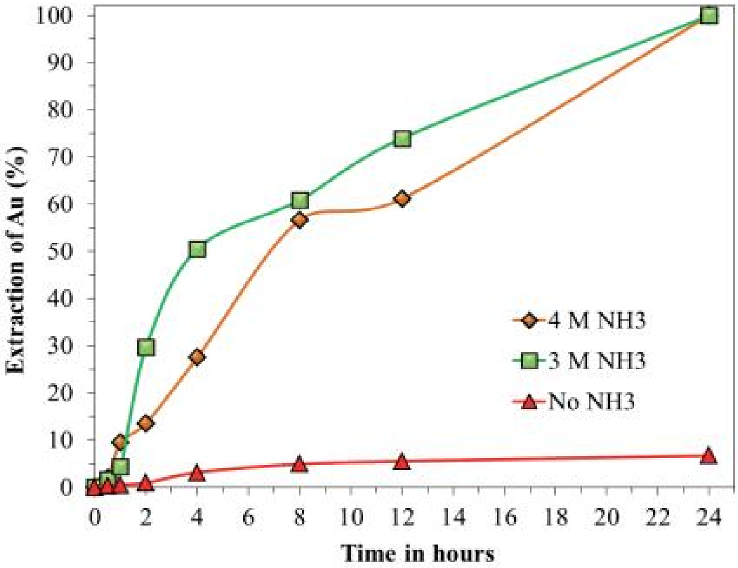

Figure 2-2 Effect of NH3 concentration in ammoniacal cyanidation of gold (1.5 g/L NaCN, pH 10.5-11, 25% w/v solids) (A. D. Bas 1, 2017)

It was consistently found that raising the ammonia concentration from 3 to 4 M slowed down the kinetics of gold leaching (Figure 2.2). By forming compounds with copper, adding, or increasing the concentration of ammonia appeared to improve the availability of cyanide for gold leaching (A. D. Bas 1, 2017).

2.2.3 Lead Nitrate Concentration

When lead nitrate ($Pb(NO_3)_2$) reacts with sulphide minerals, it creates lead sulphide, which functions as a catalyst for sulphide oxidation, freeing the lead ions to react with sulphide ions and preventing the sulphide ions from passivating the gold surface. In other words, lead ions can react with sulphide films in gold ore, causing passivated gold to become reactive even when sulphide production is not present.

Although the addition of $Pb(NO_3)_2$ can help speed up gold dissolution, a high concentration of lead can also cause passivation of the gold surface. By adding enough lead nitrate to the solution can reduce cyanide consumption by the sulphides and producing a passivation layer on the surface of the sulphide minerals and avoiding the creation of a passive layer on the surface of gold, a tiny amount of lead salt added to the cyanide leaching solution can stabilize copper and iron dissolution. Adding lead nitrate and oxygen to the gold dissolving process is also beneficial. The use of lead nitrate increases the gold dissolution kinetics considerably, as shown in Figure 2.3.

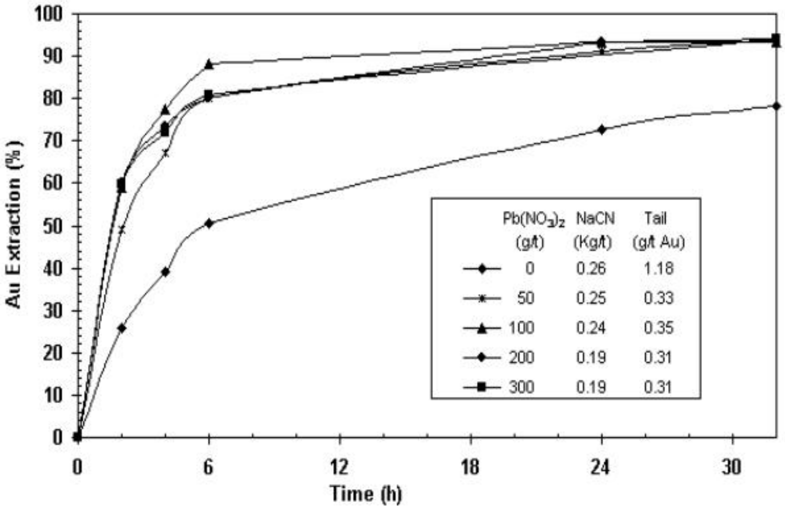

Figure 2-3 Effect of lead nitrate addition on the leaching of a pyrrhotite-bearing gold ore (Cyanidation: pH 11.2, 380ppm NaCN, 8ppm O2, 32h) (G. Deschênes1*, 2003)

With the addition of 50g/t lead nitrate, a gold extraction of 93.9 % was produced in 24 hours, compared to 78.1 % without lead nitrate. Lead nitrate promotes gold dissolution by acting on the surface of gold particles to prevent the development of a passive layer of sulphide (gold sulphide), as previously demonstrated (Deschenes G, 2012).

Although the total gold extraction stays roughly the same, increasing the $Pb(NO_3)_2$ concentration to 100g/t increases the leaching kinetics even more (93.1% vs. 93.9 %). Increases in lead nitrate concentrations above 100 g/t resulted in a slight increase in cyanide consumption and gold recovery. The gold loss appears to be slightly reduced at 0.31g/t in the leach residue, indicating a 25% reduction in cyanide use (G. Deschênes1*, 2003).

2.2.4 Pre-aeration

The amount of oxygen required for particle surface oxidation is determined by the amount and concentration of sulphide species in the ore. Particularly compared to air injection, using oxygen in the leaching stage speeds up gold dissolution, improves ultimate gold recovery in some situations, and saves cyanide, especially when oxygen is utilized during pre-aeration (Bas, 2012).

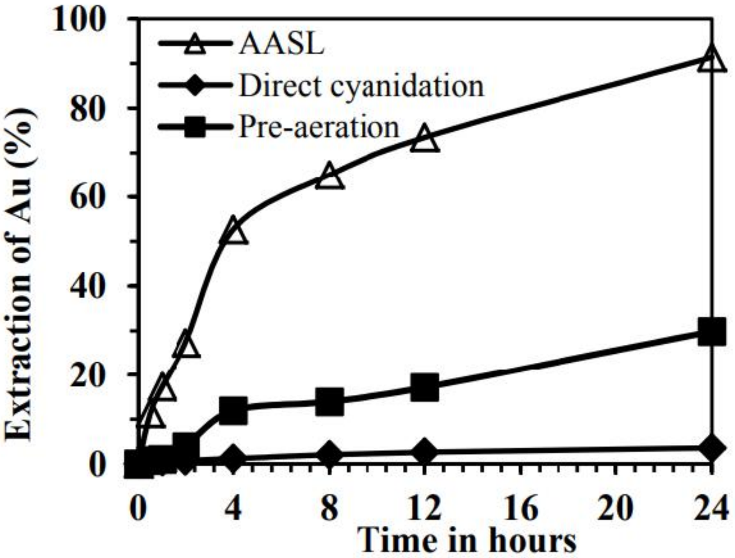

Figure 2-4 Effect of pre-aeration (2 L/min) and ammoniacal ammonium sulphate leaching (AASL) (0.5 M NH3+0.5 M (NH4)2SO4) on the extraction of gold (1.5 g/L NaCN) (Bas, 2012)

The extraction of gold increases from 4% to 30% when the ore is pre-aerated. This improvement might be related to a reduction in the sulphide ion's passivation impact. Previous research (Lia et al., 2006; Li et al., 2009). Figure 2.4 has shown that pre-oxidation/aeration of gold ores improves subsequent cyanide leaching.

2.2.5 Temperature

When the temperature rises to 40 °C, the gold extraction value increases, but at higher temperatures, the gold extraction value falls. The leaching reaction can be chemically regulated if there is enough Cu (II) ion present. As a result, by increasing the temperature to 40 °C, the gold extraction rate increased to almost 57 %. The enhancement of thiosulfate ion passivation by copper ions and their consumption may account for the reduced gold extraction at temperatures over 40 °C.

Furthermore, greater temperature rises ammonia volatilization and loss. According to certain studies, a temperature range of 25 to 55 in the thiosulfate system is optimal for gold dissolution and the avoidance of both ammonia losses and copper reduction. (Abhishek Tripathi1 Manoj Kumar2, 2012)

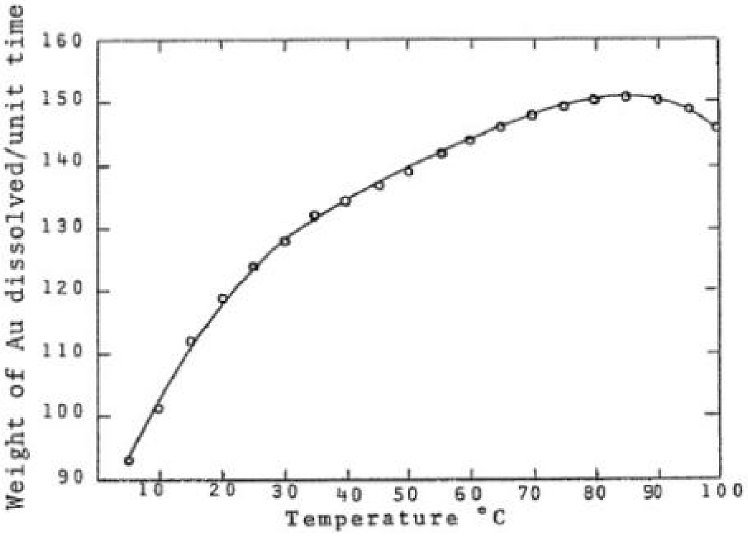

Figure 2-5 Effect of temperature on rate of dissolution of gold (Effect of Temperature on Cyanidation and Gold Leaching Kinetic Rates, 2015)

When heat is added to a cyanide solution containing metallic gold, the rate of dissolution is affected by two opposing variables. Figure 2.5 show the activity of the solution is predicted to increase as the temperature rises, increasing the rate of gold dissolution. Because the solubility of gases reduces with rising temperature, the quantity of oxygen in the solution would also decrease (Mathews, 2005).

Some researcher discovered that the rate of dissolution rose to a maximum at 85°C, even though the oxygen level of the solution was less than half that at 25°C. They also discovered that, despite the absence of oxygen in the solution, the rate of gold dissolution at 100 was only slightly less than the maximum. The capacity of an electrode to absorb or retain hydrogen at its surface is smaller in a hot solution than in a cold solution, according to the explanation supplied for this divergence from what is regarded the typical reaction for the dissolution of gold, i.e., where oxygen is deemed important.

2.2.6 pH

During the leaching process, the pH is kept between 11 and 12. pH levels below 11 encourage the development of HCN, or hydrogen cyanide, which stymies the synthesis. Hydrogen cyanide is a colourless, lethal gas that may swiftly kill if emitted owing to low pH levels. During the leaching process, the pH is kept between 11 and 12. pH levels below 11 encourage the development of HCN, or hydrogen cyanide, which stymies the synthesis.

Hydrogen cyanide is a colourless, lethal gas that may swiftly kill if emitted owing to low pH levels. Small losses in heap leaching can add up to high makeup expenses over time since cyanide is a rather costly chemical. Gas leaks into the environment are a danger to mine workers and a potential liability for the mining company that may be avoided with pH monitoring.

In ammonia leaching, pH and free ammonia concentration are important parameters controlling the dissolution process in which Cu(NH3)42+ is stable at pH 7.9-10.6 (optimum pH 9.3) (Ahmet Deniz Bas, 2015).

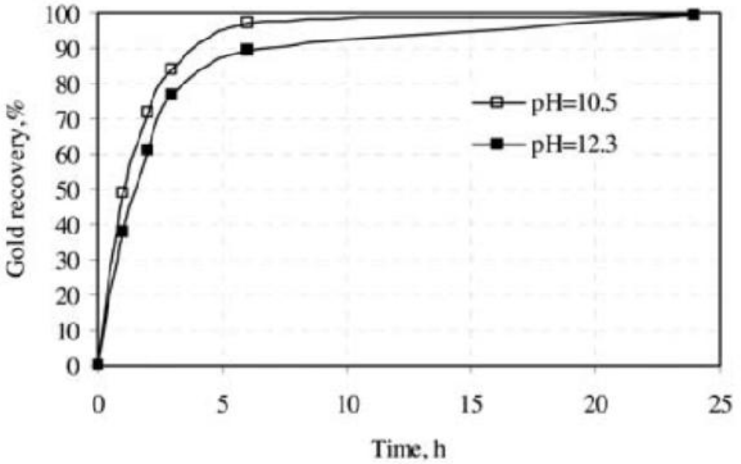

Figure 2-6Effect of pH on the leaching (B, 2005).

It was discovered that for nonrefractory ores like these, gold dissolution was certainly faster at lower pH values at the start of testing, but the ultimate gold recoveries did not vary.

2.2.7 Pulp Density

The availability of a larger quantity of the reagent per unit weight of granules has been demonstrated to be favourable to gold recovery when compared to increased pulp density evaporations. Figure 2.7 shows that these investigations revealed that a lower pulp density improves gold recovery in the solution, but a larger pulp density reduces recovery percentage.

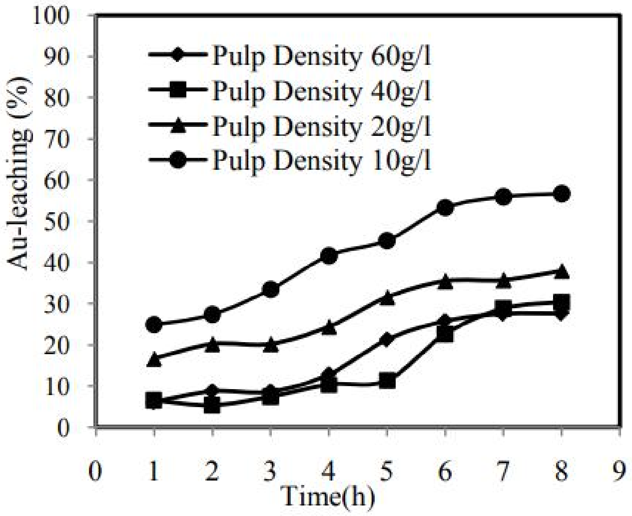

Figure 2-7 Effect of pulp density on leaching of gold with time (Abhishek Tripathi1 Manoj Kumar2, 2012)

2.2.8 Retention time

The solids retention period in the leaching system is referred to as retention time. The entire volumetric capacity of the leach tank/s is divided by the volumetric throughput of the solid/liquid slurry to arrive at this figure. For precious metals recovery, retention time is usually measured in hours. (Costello, 1992) Figure 2.8 shows the relationships between time and the percentage of gold extraction.

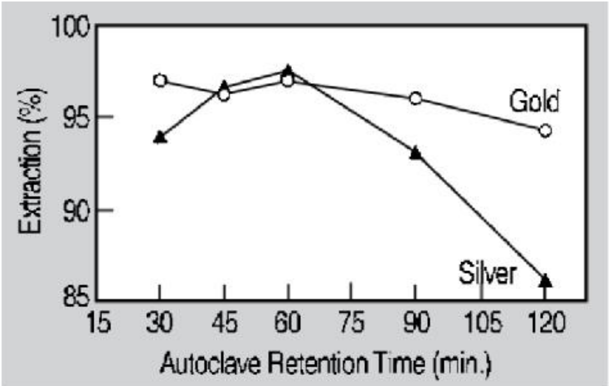

Figure 2-8 The effect of autoclave retention time on gold and silver extraction (José R. Parga, 2007)

The gold extraction rate rises with time, reaching 40% after 2 hours of leaching. As a result, a changeover after a two-hour leaching period shows a shift in the process mechanism. After 16 hours of leaching, the gold extraction rate was around 55%. Because of the high concentration of chalcopyrite and pyrite in the ore, a long pre-leaching time with lead nitrate was necessary without oxygen enrichment of the pulp. (José R. Parga, 2007)

2.3 General Description of Ammoniacal Cyanide Leaching

2.3.1 Ammoniacal Cyanide Leaching Mechanism and Reactions

The ammoniacal-cyanidation leaching approach, which is a cost-effective process, was developed to successfully treat a gold mine containing copper oxide. Furthermore, when ammonia was added, even with half the amount of cyanide used in traditional cyanidation, far more gold was recovered. (B, 2005)

The most prevalent ore type is gold-copper ores, with gold being the most expensive metal and copper being a distant second (O Khmelnitskaya1, 2010). Cyanide leaches all copper minerals linked with gold to varying degrees at 25 ranging from 5% to 10% for chalcopyrite to >90% for most oxide copper minerals. These minerals consume about 30 kg/t NaCN for every 1% reactive copper present, which often makes conventional cyanidation of copper–gold ores uneconomic (Vukcevic, 1996).

After cyanidation for any of the alternatives, a considerable part of copper minerals reacts strongly with alkaline cyanides. This procedure binds the CN^- ions to copper complexes. As a result, cyanide consumption increases, and problems with cyanide detoxification in tailings solutions and ore slurries occur because of high-toxic cyanide compounds and dissolved copper (Dawson, 1997). There are very strict maximum allowable concentrations for it. As a result, copper in gold-copper ores and ore concentrates is both a desirable and a dangerous contaminant (Weichselbaum J, 1989).

The ammonia–cyanide leach process, developed over a century earlier, is a one-of-a-kind methodology of preferentially leaching up to 90% Au and 1% Cu from oxidized copper–gold ores using the same 10% NaCN used in standard cyanidation (Muir, 2010). Numerous processes have been investigated in recent years to address the issues caused by copper mineral dissolution during gold extraction. For a particular application, many of them have shown successful implementation (Marsen J O, 2006).

The use of an ammonia cyanide combination can reduce cyanide consumption to 0.5-1.5 kg/t NaCN at the expense of 4 kg/t NH_3, resulting in gold recoveries of 80-90 percent. The solution to the issue is to employ ammoniacal-cyanide leaching, which minimises sodium cyanide consumption (Ahmet Deniz Bas, 2015).

Copper cyanidation is more rapid than gold cyanidation, resulting in cyanide reduction and a delay in gold leaching. Ammonia in the system yields Cu^-NH_3 species, which has a thermodynamic advantage over Cu^-CN species and allows for greater Cu (1) cyanide ion stability (Akmirza, 2014). The addition of NaCN to the ore in stages increased gold recovery and copper mineral dissolution, however reprocessing the copper solution after gold extraction hindered gold extraction since the copper concentration in the solution increased considerably (Abhishek Tripathi1 Manoj Kumar2, 2012).

Prior to cyanide leaching of gold, pre-leaching of ore can be done to eliminate reactive copper minerals. Equation 2 show copper is removed by cyanide leaching without aeration before gold extraction and then adsorption on activated carbon (A. D. Bas 1, 2017).

$$2Cu^{+} + 8CN^{-} \rightarrow 2Cu(CN)3^{2-} + (CN)2 \quad \text{Equation 2}$$

As indicated by this equation, one mole of Cu(I) oxidises one mole of cyanide and combines three moles of cyanide, lowering the concentration of free cyanide for gold dissolution (Costello, 1992).

The stabilisation of Cu^{2+} as $Cu(NH_3)_4{}^{2+}$, which also served as an oxidant, was credited with ammonia's profound contribution. The precipitation of copper as $3Cu(NH_3)_3(CN)_4$ appears to be connected to the selectivity of ammoniacal cyanide leaching for gold (Deng, 1995). The equations (1) until (5) shows the excessive cyanide consumption is attributed to the production of very stable copper cyanide complexes, which are addictive and harmful (Fuerstenau, 2000).

Sulphite, sulphate, sulphide, polythionates ($S_xO_6{}^{2-}$), and polysulfides ($S_x{}^{2-}$), as well as other sulphur-containing species, will be produced in vast amounts. The presence of them in leach solutions is detrimental to gold leaching because they can produce a dense passivation layer on the gold surface, obstructing gold leaching (Ahmet Deniz Bas, 2015). Gold recovery from leach solution is especially difficult due to the presence of a significant number of disruptive ions in traditional copper-ammonia catalysed leaching (A. D. Bas 1, 2017).

The competitive adsorption of undesired anions on the resin surface, primarily $[Cu(S_2O_3)_3]^{5-}$ and $S_xO_6^{2-}$ with $[Au(S_2O_3)_2]^{3-}$, is unavoidable. As a result, gold adsorption on the resin is disrupted, making gold desorption from the laden resin more difficult. As a result, a large cost for gold recovery is required, which is another issue that restricts the use of thiosulfate leaching in industry (E.A. Oraby, 2016).

2.3.2 Quality Specifications and Analysis

2.3.2(a) Sampling

Accurate determination of gold content depends on proper sampling method. the exact procedure was determined during sampling whether using drilling, cutting, or sawing. Samples must be taken several places around the area to avoid errors. The procedure of selecting a fraction (ore sample) in such a way that its composition reflects the average composition of the overall bulk of ore (Ore sampling method, n.d.).

Moisture samples should be obtained with the same care as metallic content samples, and moisture samples should be taken from the sample-safe to prevent the added expenditure of a separate operation. Because the sample arrives at the sample bin in a smaller stream and over a more roundabout route than the " reject" does on its way to the outgoing vehicle, it loses more moisture enroute, and a constant should be applied to compensate for this. Experiments have showed that the difference in moisture loss between the two pathways is less than ten percent in summer and seven percent in winter (Ore sampling method, n.d.).

Whether for exploration, resource assessment, grade control, or plant design and balancing, the mining sector gathers samples on a regular basis to aid decision-making. By increasing variability, poorly designed sample techniques can increase project risk.

2.3.2(b) Quantitative Analysis

Quantitative analysis is the process of determining the absolute or relative abundance (typically stated as a concentration) of one, many, or all the substances contained in a sample in analytical chemistry. After verifying the existence of compounds in a sample, researchers might look at their absolute or relative abundance to determine certain qualities. Knowing the composition of a sample is critical, and numerous methods for doing so have been developed, including gravimetric and volumetric analyses.

Gravimetric analysis provides more precise information about a sample's composition than volumetric analysis, although it takes longer in the lab. Volumetric analysis, on the other hand, takes a short amount of time and can yield excellent findings. Volumetric analysis can be a simple titration based on a neutralization reaction, but it can also be a precipitation or a complex forming reaction, as well as a redox titration.

However, each quantitative analytical technique has a general definition; for example, in neutralization reactions, the reaction happens between an acid and a base, yielding a salt and water, thus the name. The standard solution in precipitation experiments is usually silver nitrate, which is employed as a reagent to react with the ions in the sample and generate a very insoluble precipitate.

Precipitation techniques are commonly referred to as argentometry. The scenario is the same in the other two techniques. The reaction between metal ions and a standard solution, which is usually EDTA, is known as complex forming titration (Ethylene Diamine Tetra Acetic acid). In a redox titration, an oxidizing agent and a reduction agent are used to carry out the reaction. There are several ways for estimating organic compounds, such as the Liebig method, Duma's approach, Kjeldahl's method, and Carius method.

2.4 Full Factorial Design of Experiment (DOE)

A complete factorial design is one in which researchers assess responses at all factor level combinations. Minitab provides two different forms of complete factorial designs: Two-level complete factorial designs using only two-level elements. universal complete factorial designs with more than two tiers of factors.

A complete factorial design is a straightforward systematic design approach that enables for the assessment of main effects and interactions. This design is quite beneficial, but it necessitates a huge number of test points as the levels or number of elements rise.

An ANOVA table is often used to present ANOVA findings. ANOVA tables include the following information:

1) Source: the causes of variance, which include the component under consideration (in our instance, lot), error, and total.

2) DF: the number of degrees of freedom for each source of variation.

3) Sum of Squares: compute the sum of squares (SS) for each source of variation, as well as the total of all sources.

4) Mean Square: the total of squares divided by the number of degrees of freedom.

5) F ratio is calculated by dividing the mean square of the factor (lot) by the mean square of the error.

6) The p-value is represented by Prob > F.