Thiosulphate Stability
In Gold Leaching Process

by

Chen Xia

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Abstracts

Ammonium thiosulphate is an alternative gold leaching lixiviant used to replace cyanide. The current problem of thiosulphate gold leaching is the high reagent consumption. To understand the decomposition chemistry of thiosulphate, solution stability tests were conducted in open and sealed vessels under ambient temperature and normal pressure conditions. A low-grade mild refractory copper-bearing gold ore containing pyrite and chalcopyrite minerals was used in this study. Other types of gold ores were selected to confirm the results.

The main compounds of thiosulphate lixiviant are ammonium thiosulphate, ammonia and cupric ion. The copper ion is a catalyst in gold dissolution and also a major component causing the decomposition of thiosulphate. The copper concentration at 0.03M gave an optimum gold extraction of 79% with 29kg/t of thiosulphate consumption. When the copper concentration was reduced to 0.0015M or lower, the thiosulphate consumption was reduced to 17kg/t without affecting the gold extraction. The addition of reducing agents and chelating agents also reduce the thiosulphate consumption. The addition of EDTA at 0.03M reduces thiosulphate consumption by 30% to 23kg/t with an increase in gold extraction up to 88%. Under the same conditions, more than 7kg/t of thiosulphate was saved in gold leaching of a high-grade sulphide gold ore with a 2% increase of the gold extraction. By decreasing the concentrations of EDTA and copper sulphate to 0.0015M or lower, the improvement of EDTA on thiosulphate consumption and gold extraction became insignificant. Sulphite addition could improve the thiosulphate stability slightly. The addition of sulphite at 0.2M gave 81% of gold extraction with thiosulphate consumption at 26kg/t. The excessive addition of sulphite might reduce the gold extraction of a high-grade gold ore to 62% with a thiosulphate consumption of 19kg/t. Sulphate addition could not improve the thiosulphate stability significantly. Gold leaching at high pulp density (62%) produced the same gold extraction and greatly reduced the thiosulphate consumption to 13kg/t. The mineral content of the ore also influenced the gold extraction capacity. Sulphide minerals were responsible for lower gold extraction and thiosulphate consumption. The increase of oxide minerals consumes more thiosulphate. Roasting the sulphides increases the thiosulphate stability and gold extraction capacity. The oxygen control by applying nitrogen flow in the pulp at a flow rate of 5ml/min leads to an acceptable gold extraction of 85% with only 10kg/t of thiosulphate consumption. The regeneration of thiosulphate from pregnant solution by zinc precipitation was observed. The addition of 0.3125g of zinc powder could precipitate most dissolved copper in 50ml of pregnant solution containing 0.03M of copper sulphate. About 0.025M of thiosulphate was regenerated in less than 7 minutes during zinc precipitation.

A decomposition chemistry model was established to explain the thiosulphate multi-level oxidation. Tetrathionate is the primary product when dissolved copper exists. Sulphite and sulphate are the secondary and final products. The balance among these species is complicated. Copper ion and its complexes act as oxidation catalysts. Tetrathionate decomposes to thiosulphate and sulphite when copper ion is replaced by zinc. In the absence of copper, the primary decomposition product of thiosulphate is sulphite.

Abbreviations

TS	Thiosulphate
TT	Tetrathionate
DO	Dissolved oxygen
ZnPP	Zinc Precipitation

Acknowledgments

I would like to express my most sincere thanks to my supervisor, Dr. W.T.Yen for his guidance, advice and trust throughout the course of this research.

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1. Introduction

1.1 Cyanidation and Its Problems

Cyanidation has been recognized as the major gold leaching method for over 100 years. Due to low dosage requirements, simpler reaction chemistry and better metallurgical performance, cyanidation is successfully applied in modern gold mines. However, cyanide is a very hazardous toxic reagent with environmental safety problems. The following three problems make researchers to find the alternative lixiviants, such as halogen, hyperchloride, thiourea and thiosulphate.

A. High cyanide and oxygen consumption on ores with cyanacide impurities.

Copper, arsenic, antimony, zinc and nickel may dissolve in the cyanide solution and consume a large amount of reagent and oxygen and is also responsible for the low gold extraction. For a copper-bearing gold ore, the dissolution of copper minerals will replace and precipitate the extracted gold and consume more cyanide reagent by the formation of copper cyanide complexes.

B. Low gold recovery from the carbonaceous refractory ore.

Elemental carbon or graphite materials in the ores will adsorb gold and silver from the pregnant solution. Gold may adsorb on these carbonaceous materials and be lost to the residue.

C. Environmental threats

Strict environmental regulations have been introduced and enforced by government to control the potential threats to our mother earth. Cyanide is not only an extremely toxic chemical to living species but also an extracting agent for several metal ions from minerals and produce hazardous metal cyanide complex. The toxicities of free cyanide and the metal complexes force the gold mines to invest a lot of money on environmental protection. Even with these environmental protection investments, there have been many disasters during the last several years. Many gold mines were forced to pay fines to the government and local residences because of chemical spills. Thus, environmentalists are continuously calling for a ban on cyanide use.

1.2 Thiosulphate Gold Leaching Process

Thiosulphate leaching may decrease the interference caused by metal impurities, carbonaceous materials, and especially copper minerals. Thiosulphate is considered as a non-toxic lixiviant. At the same time, many researchers report faster gold leaching rates than cyanidation. Based on the above considerations, thiosulphate gold leaching is looked at as one of the most promising replacements for the cyanidation process.

The dissolution of gold in thiosulphate solution has been recognized for over 100 years. In the early 1900s, thiosulphate leaching was applied to gold and silver ores after a chloride roasting process. In the late 1970s, the catalysis function of copper was implemented. Berezowsky et al. (1979) and Kerry et al. (1981) developed and patented an ammonium thiosulphate leaching process, which is mainly applied on copper bearing ores. Tozawa et al. (1981) suggested an optimum condition at 65 °C with an oxygen overpressure of 100kPa. More recent work has been focused on the atmospheric ammonium thiosulphate leaching process. Jiang et al. (1993), Langhans et al. (1992), Gundilier et al. (1993), Wan et al. (1994), Abbruzzese et al. (1995) and Yen et al. (1996) investigated the possibility of ambient temperature gold leaching with a longer retention time. The Newmont Gold Co. successfully operated a heap leaching process on carbonaceous ore with bio-oxidation followed by thiosulphate gold leaching at atmospheric condition. They applied copper tetra amine as the catalyst for gold extraction. To reduce thiosulphate consumption, several researchers applied additives to the system. Sulphite and sulphate salts were studied by Hemmati et al (1989), Hu at al (1991). Amino acids were investigated by Didier Michel and Jean Frenay (1998). The improvements by these additives were not conclusive.

The good performance of thiosulphate leaching on copper-bearing ores, carbonaceous refractory ores and low-grade ores has been reported and ensured thiosulphate a promising future industry application. But there are still some problems to be solved prior to practical application.

A. How to economically recover the gold from the pregnant solution?

Researchers have tried different methods of gold recovery. Carbon adsorption and resin ion exchange didn't give an acceptable recovery. Zinc, copper and iron powder cementations have been reported to be good choices for gold recovery from thiosulphate pregnant solution. Recently, new solvent extraction methods are reported to be another choice for gold recovery. The evaluations of those recovery methods must be done before worldwide use of thiosulphate as the lixiviant of gold extraction can be considered.

B. How to control the reagent consumption?

High thiosulphate and copper sulphate consumptions prohibit the practical application of thiosulphate as a lixiviant. Gold extraction is generally a series of oxidation reactions requiring high oxygen supply. The problem is that thiosulphate itself is a kind of weak reducing agent and readily decomposes in the presence of oxygen. Thus, researchers must explore ways to control the solution stability and reduce the thiosulphate consumption without affecting gold extraction. Yen et al. (2001) calculated the cost of reagent in the thiosulphate gold leaching process and compared it with cyanidation. Based on the current chemical market prices, the ammonium thiosulphate consumption must be less than 10kg/t to be comparable to cyanidation, regardless of the reagent recycling and copper self-supply by mineral dissolution in ammonia solution.

1.3 Objective of This Investigation

The objective of this research was to study gold extraction by thiosulphate, variables affecting thiosulphate decomposition and methods to reduce reagent consumption.

For a better understanding of thiosulphate decomposition, a series of thiosulphate solution decomposition tests were conducted. The effects of variables and additives on thiosulphate stability were evaluated. The reagent regeneration by zinc precipitation was studied. A possible decomposition model was investigated. The results were applied in gold leaching tests. Effects of copper ion and its complexes on both gold leaching and thiosulphate stability were also investigated. Gold leaching in solutions with low reagent strength was studied. Effective additives including sulphur compounds and chelating agents were tested and compared. Studies on oxygen supply, ore types, and pulp density were additionally investigated.

2. Literature Review

2.1 Gold Extraction by Thiosulphate

The dissolution of gold in thiosulphate solution has been reported for over 100 years. In the 1900s, the Von Patera Process applied thiosulphate leaching on gold and silver ore after a chloride roasting. This method had been used in South America prior to World War II. In the late 1970s, Berezowsky et al. (1979) and Kerly et al. (1981) developed and patented an ammonium thiosulphate leaching process for treating a copper bearing gold ore. The leaching at this early stage was performed at a high temperature and pressure to prevent precipitation of sulphur and metal sulphide. Tozawa, et al (1981) investigated the gold plate dissolution behaviours under various temperature and oxygen overpressure conditions. Their optimum condition was 65 °C with oxygen overpressure of 100kPa. Zipperian et al. (1988) and Hemmati et al. (1989) also reported that similar conditions could extract gold from a copper bearing or carbonaceous gold ore. The temperature in the range of 50 to 60 °C was limited in laboratory scale and not practical in a large production scale. The atmospheric ammonium thiosulphate leaching process was developed in the late 1980's and 1990's. Jiang et al. (1993), Langhans et al. (1992), Gundilier et al. (1993), Wan et al. (1993), Abbruzzese et al. (1995) and Yen et al. (1996) have demonstrated the possibility of ambient temperature gold leaching with thiosulphate at a longer retention time. The Newmont Gold Co. has successfully operated a bio-oxidation process on a carbonaceous ore followed by gold leaching with thiosulphate solution at atmospheric conditions. Copper tetra amine has been patented as a catalyst for gold extraction. For reducing thiosulphate consumption, several researchers have tried some additives to the thiosulphate leaching system. Sulphite and sulphate salt were studied by Hemmati et al (1989) and Hu at al (1991). Amino acids were investigated by Didier Michel and Frenay (1998). The improvement on thiosulphate stability by these additives is encouraging but not conclusive.

2.2 Chemistry of Gold Leaching by Ammonium Thiosulphate

It is well known that thiosulphate forms strong complexes with Au (I), Cu (I), Bi (II), Hg (II) and Fe (III). In the presence of ammonium thiosulphate, gold is eventually dissolved as thiosulphate complex (Hiskey and Atluri, 1988).

The copper ions in thiosulphate solution can be reduced to cuprous ion and complex with thiosulphate (Tykodi, 1990). When the oxygen supply is sufficient, cupric ammonia complex is more stable than cuprous thiosulphate complex.

Yen, et al (1996) summarized the gold extraction chemistry as an electrochemical redox reaction. Gold extraction is a metal corrosion reaction catalysed by copper ion in ammonia solution.

In the anodic area, the gold is oxidized and complexed with ammonia. This complex is instantly replaced by a more stable gold thiosulphate complex. The chemical reactions are shown as below.

The anodic reactions are:

$$Au \rightarrow Au^{+} + e^{-} \tag{2-1}$$

$$Au^{+} + 2NH_3 \rightarrow Au(NH_3)_2^{\ +} \tag{2-2}$$

$$Au(NH_3)_2^{\ +} + 2S_2O_3^{\ 2-} \rightarrow 2NH_3 + Au(S_2O_3)_2^{\ 3-} \tag{2-3}$$

In the cathodic area, the cupric amine complex ion is reduced to cuprous ion and the oxygen in the ammonia solution oxidizes the cuprous complex to cupric complex.

The cathodic reactions are:

$$Cu(NH_3)_4^{\ 2+} + e^{-} \rightarrow Cu(NH_3)_2^{\ +} + 2NH_3 \tag{2-4}$$

$$4Cu(NH_3)_2^{\ +} + 8NH_3 + O_2 + 2H_2O \rightarrow 4Cu(NH_3)_4^{\ 2+} + 4OH^{-} \tag{2-5}$$

Both ammonia and cupric amine are recycled in the system. The reactions in the anodic and cathodic area could be summarized as follows:

$$4Au + 8S_2O_3^{\ 2-} + O_2 + 2H_2O \rightarrow 4Au(S_2O_3)_2^{\ 3-} + 4OH^{-} \tag{2-6}$$

This reaction is the same as the reaction of gold leaching in the cyanide solution. All above reactions can be simply explained by Figure 2-1.

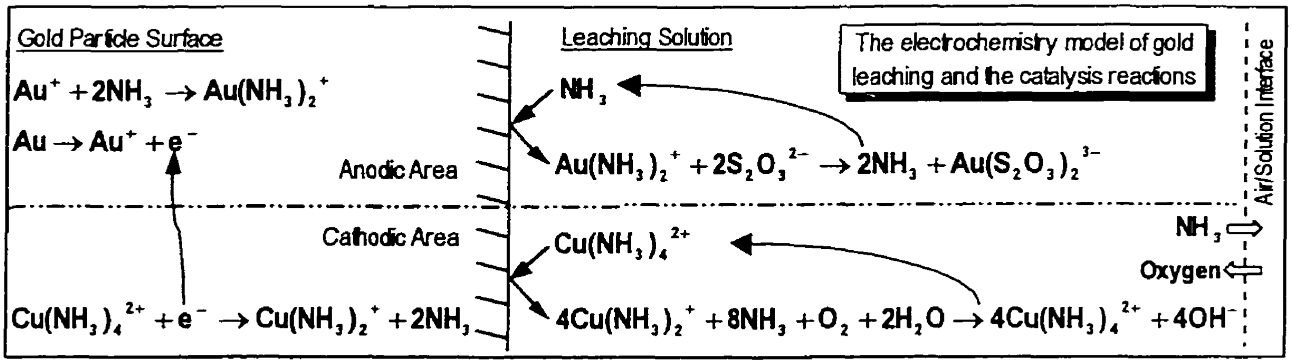

Figure 2-1 The Electrochemical Model of Gold Leaching and Catalysis

Zipperian and Raghavan (1988) published the Eh-pH diagrams of the thiosulphate-copper-ammonia system as shown in Figure 2-2 to Figure 2-6. The effects of ammonia, Cu^{2+} and thiosulphate were studied in Au-S-NH_3 and Cu-S-NH_3 systems.

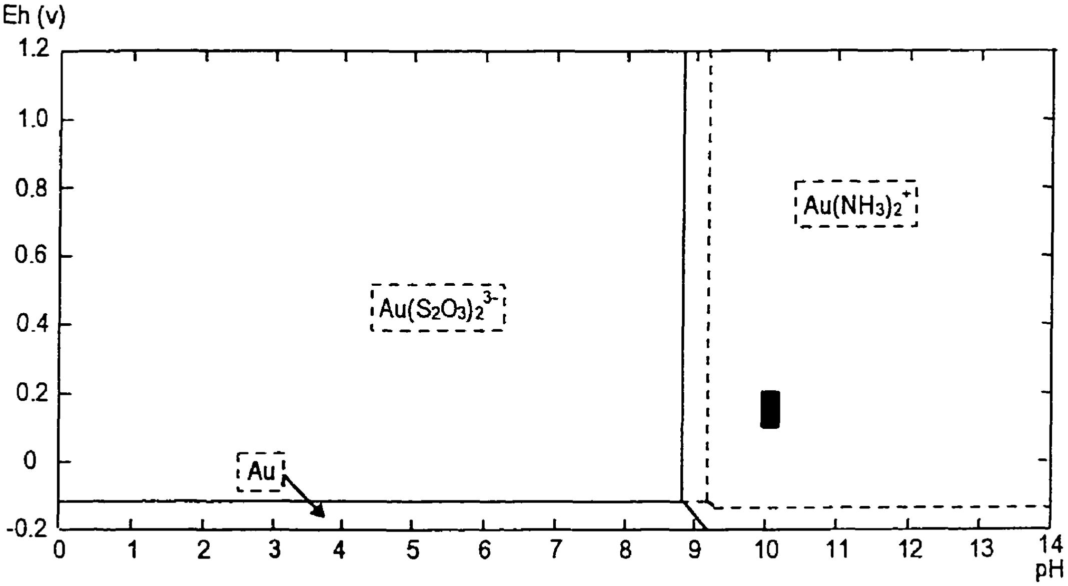

Figure 2-2 Eh-pH Diagram for Gold-thiosulphate-ammonia System

(5mg/kg Au, 1M thiosulphate, Dashed-line: 1M Ammonia/Ammonium ion, Real-line, 3M Ammonia/Ammonium ion) Zipperian and Raghavan (1988)

Figure 2-2 shows the effect of ammonia on the stability of gold complexes. The most stable species under the typical leaching conditions (demonstrated as the shaded square) was the gold (I) ammonia complex. The increase of ammonia/ammonium ion concentration from 1 to 3M expanded the stable area of gold ammonia complex.

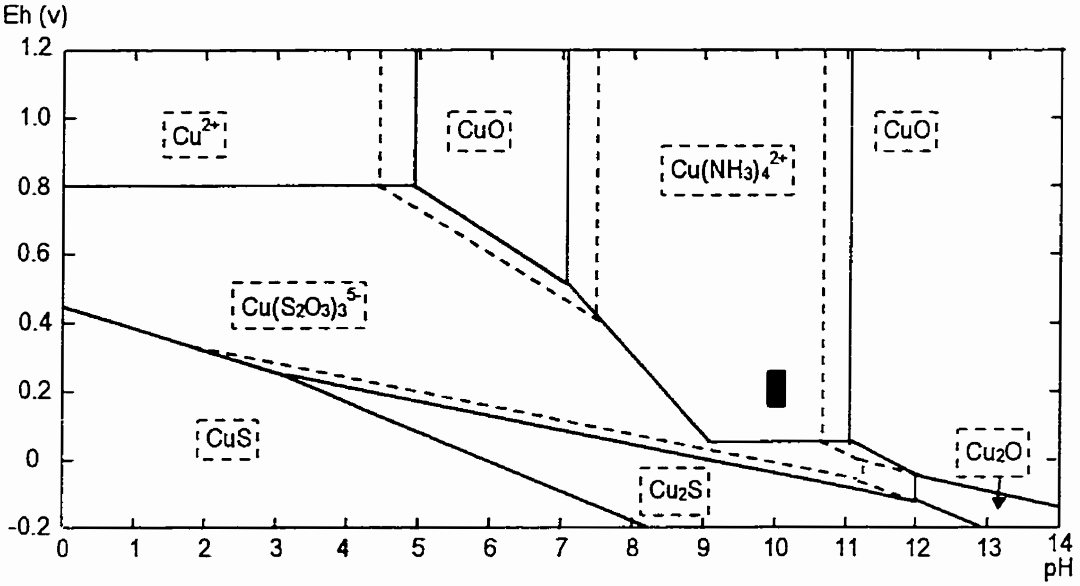

Figure 2-3 Eh-pH Diagram for Copper-thiosulphate-ammonia System

(Real-line: 0.1M thiosulphate, 6.3mM cupric ion, 1M ammonia/ammonium ion; Dashed-line: 0.1M thiosulphate 0.05M cupric ion, 1M ammonia/ammonium ion) Zipperian and Raghavan (1988)

Figure 2-3 shows that the most stable species under typical leaching conditions (demonstrated as the shaded square) was copper tetra amine. When the thiosulphate concentration is low (0.1M), the increase of cupric ion concentration from 6.3mM to 0.05M narrowed the stable area of copper tetra amine.

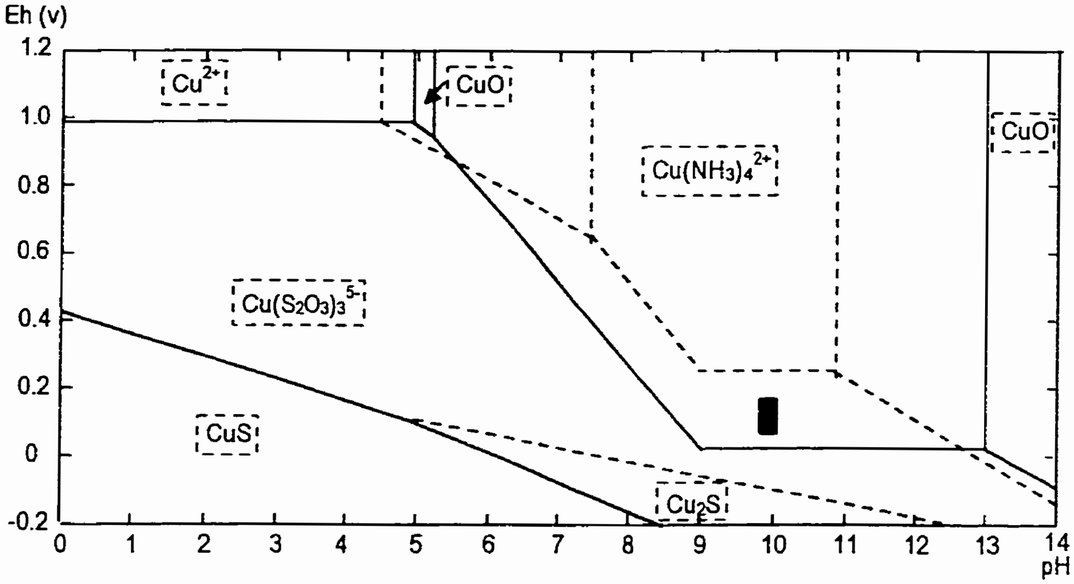

Figure 2-4 Eh-pH Diagram for Copper-thiosulphate-ammonia System

(Real-line: 1M thiosulphate, 6.3mM cupric ion, 1M ammonia/ammonium ion; Dashed-line: 1M thiosulphate, 0.05M cupric ion, 1M ammonia/ammonium ion)

Zipperian and Raghavan (1988)

Figure 2-4 shows that the most stable species under typical leaching conditions (demonstrated as the shaded square) was copper tetra amine. When the thiosulphate concentration was high (1M) and the cupric ion concentration increased from 6.3mM to 0.05M, the copper tetra amine window was narrowed and moved upwards so that copper tetra amine was no longer the most stable species under the typical leaching conditions.

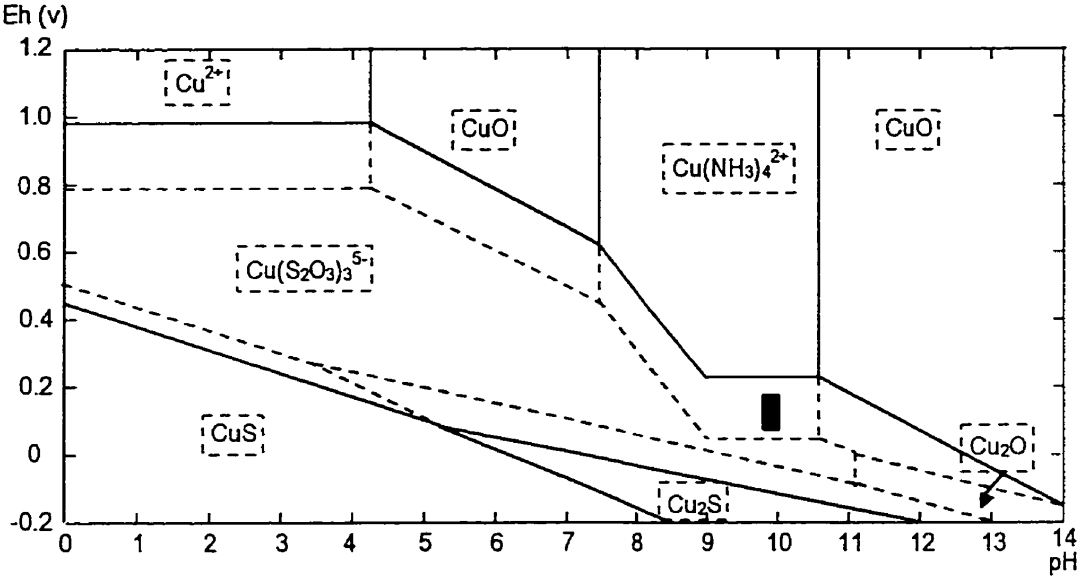

Figure 2-5 Eh-pH Diagram for Copper-thiosulphate-ammonia System

(Real-line: 1M thiosulphate, 0.05M cupric ion, 1M ammonia/ammonium ion; Dashed-line: 0.1M thiosulphate, 0.05M cupric ion, 1M ammonia/ammonium ion)

Zipperian and Raghavan (1988)

Figure 2-5 shows that the most stable species under typical leaching conditions (demonstrated as the shaded square) was copper tetra amine. When the thiosulphate concentration increased from 0.1M to 1M, the copper tetra amine window was narrowed and moved upwards so that copper tetra amine was no longer the most stable species under the typical leaching conditions.

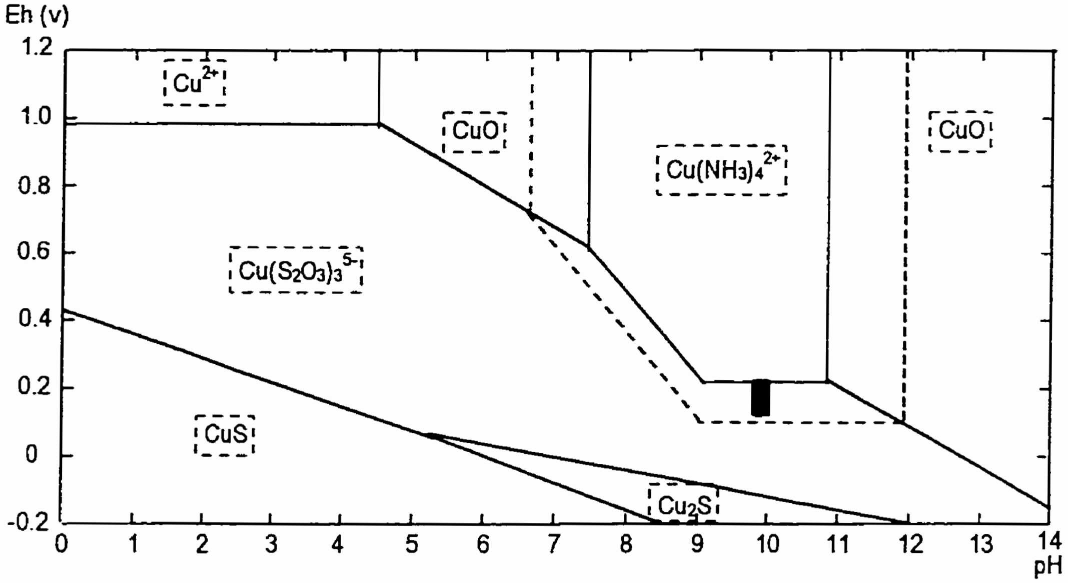

Figure 2-6 Eh-pH Diagram for Copper-thiosulphate-ammonia System

(Real-line: 1M thiosulphate, 0.05M cupric ion, 1M ammonia/ammonium ion, Dashed-line: 1M thiosulphate, 0.05M cupric ion, 3M ammonia/ammonium ion)

Zipperian and Raghavan (1988)

Figure 2-6 shows that the most stable species under typical leaching conditions (demonstrated as the shaded square) was copper tetra amine. When the thiosulphate concentration was high (1M) and the ammonia/ammonium ion concentration was reduced from 3M to 1M, the copper tetra amine window was narrowed and moved upwards so that copper tetra amine was no longer the most stable species under the typical leaching conditions.

It could be concluded from the above Eh-pH diagrams that to maximize the gold leaching speed, the gold dissolution catalyst, copper tetra amine should be the most stable copper complex under the typical leaching conditions. So, a low thiosulphate and copper concentration and a high ammonia/ammonium ion concentration are preferred.

As shown in Figures 2-7 to 2-9, Aylmore and Muir (2001) presented the Eh-pH diagrams of Au-S-NH_3 and Cu-S-NH_3 systems for both high and low reagent concentrations. The high concentration lixiviant consisted of 1M of thiosulphate, 1M of ammonia and 0.05M of cupric ion. The low concentration lixiviant was contained 0.1M of thiosulphate, 0.1M of ammonia and 0.5mM of cupric ion.

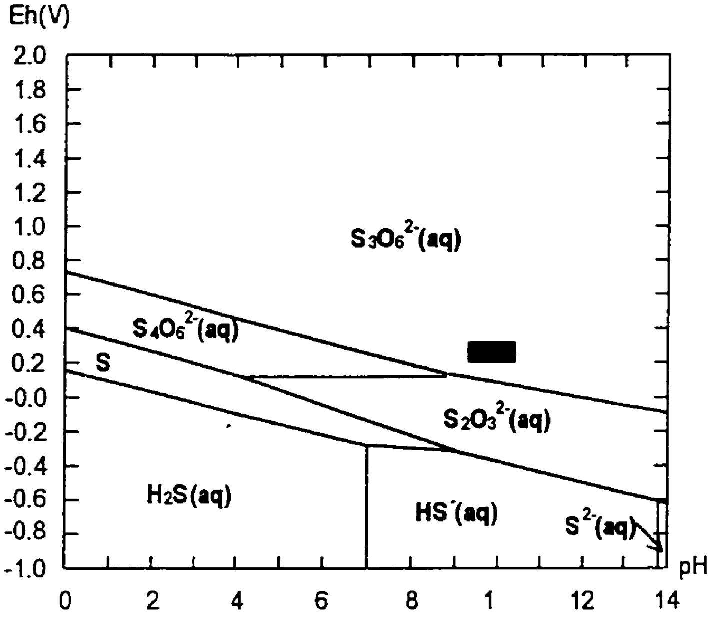

Figure 2-7 Eh-pH Diagram for Meta-stable Sulphur-water System
({S}=1.0M) Aylmore and Muir (2001)

Figure 2-7 shows that thiosulphate is not stable in aqua solution under the typical leaching conditions (shown as the shaded square). In the pH range from 9 to 11, trithionate was supposed to be the direct decomposition products. The presence of excess oxygen should increase Eh and favour increased formatio of trithionate.

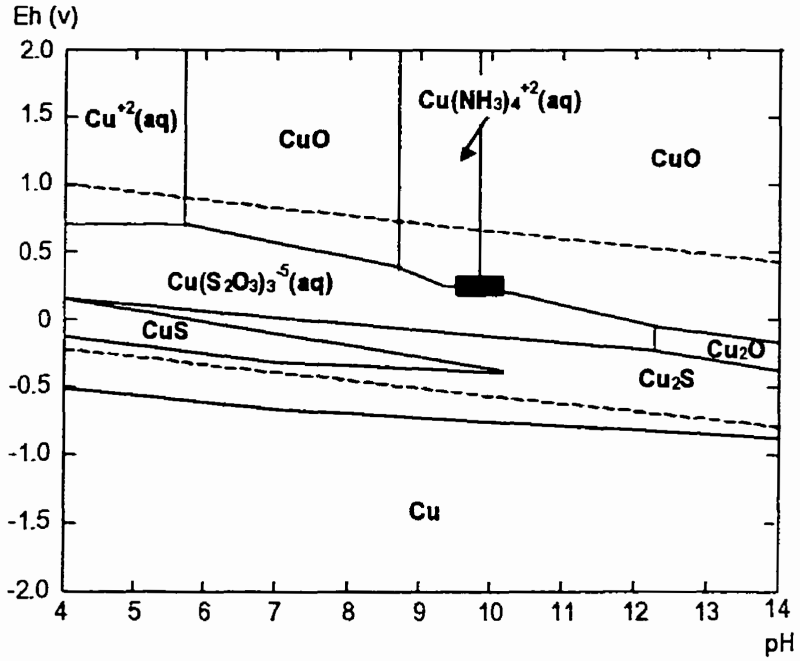

Figure 2-8 Eh-pH Diagram at Low Reagent Concentration for Copper-ammonia-thiosulphate System

($5*10^{-4}$ M Au, 0.1M thiosulphate, 0.1M ammonia/ammonium ion, $5*10^{-4}$ M cupric ion)

Aylmore and Muir (2001)

Figure 2-8 shows that in low reagent concentration lixiviant, the most stable species under the typical leaching conditions (demonstrated as the shaded square) were copper tetra amine, cuprous thiosulphate complex and CuO. The copper tetra amine window was very narrow. The leaching condition should be limited in the pH range from 8.5 to 10 in order to stabilize copper tetra amine.

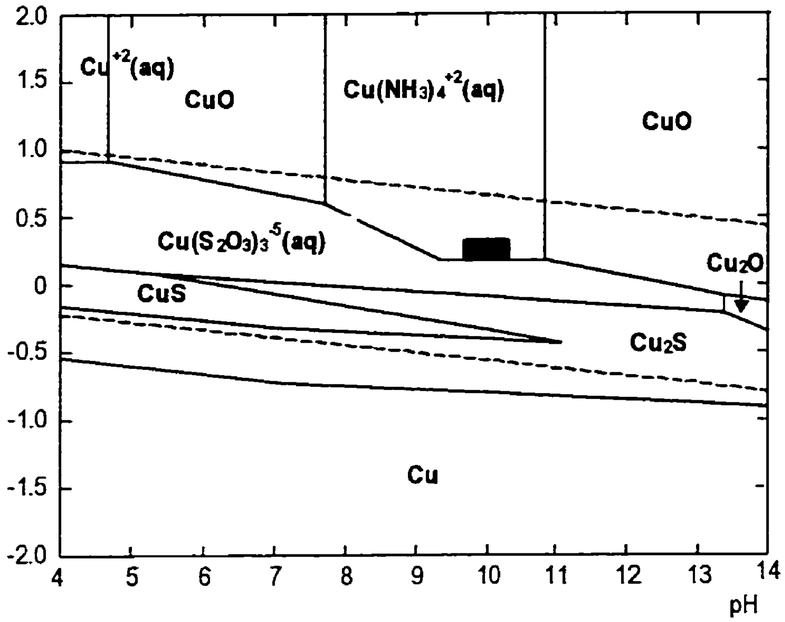

Figure 2-9 Eh-pH Diagram at Low Reagent Concentration for Copper-ammonia-thiosulphate System

(5*10^{-4} M Au, 1M thiosulphate, 1M ammonia/ammonium ion, 5*10^{-4} M cupric ion)

Aylmore and Muir (2001)

Figure 2-9 shows that, in high reagent concentration lixiviant, the most stable species under the typical leaching conditions (demonstrated as the shaded square) was copper tetra amine. As compared to Figure 2-8, copper tetra amine was stable in a wider range of pH from 8 to 11.

2.3 A Review on the Chemistry of Thiosulphate Decomposition

2.3.1 Thiosulphate Properties

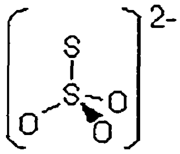

Figure 2-10 Structure of Thiosulphate Anion

As shown in Figure 2-10, the thiosulphate anion is a natural donor to form sulphite and sulphur. The conventional use of thiosulphate is mainly as a weak reducing agent. Thiosulphate may help to remove the excess chlorine in paper and textile bleaching. It has also been applied in preservation of soap and the preparation of matches. In environmental protection and medical areas, thiosulphate can help to remove cyanide and arsenic poisons. The other important usage of thiosulphate is as a fertilizer for soils low in sulphur. Thiosulphate is reported to be a solvent of precious metals in photography and electroplating. (Dhawale, 1993)

In gold leaching reactions, thiosulphate was mainly a complex agent with the following two attributes.

A. Trend to form complex with metal ions

Thiosulphate can form stable complexes with many metal ions, such as gold, silver (I), copper (I), iron (III), nickel and cobalt. This is the basic principle of gold extraction by thiosulphate. (Tykodi, 1990), as shown by the following reactions:

$$Au(NH_3)_2^{+} + 2S_2O_3^{2-} \rightarrow 2NH_3 + Au(S_2O_3)_2^{3-} \qquad (2\text{-}7)$$

Copper may compete with gold to form complexes with thiosulphate anions, such as $Cu(S_2O_3)_3^{5-}$ and $Cu(S_2O_3)_2^{3-}$. In neutral or alkali solutions, $Cu(S_2O_3)_3^{5-}$ is the predominant species (Aylmore and Muir, 2001). In the presence of ammonia, in a solution with a pH lower than 8.5, copper forms complexes with thiosulphate. In a solution with a pH higher than 8.5, copper thiosulphate complexes will be replaced by a copper amine complexes. Oxygen-enriched solution may increase the level of oxidation potential and decrease the copper thiosulphate complex stability. When the oxidation potential is higher than 0.4, the copper amine complexes become the predominant complexes. This balance between copper amine complex and copper thiosulphate complex is influenced by ammonia concentration and thiosulphate concentration. Copper tends to form complexes with thiosulphate when there is more thiosulphate or less ammonia.

B. A meta-stable weak reducing agent

Thiosulphate is a meta-stable anion that tends to undergo chemical decomposition in aqueous solutions. Many factors influence the stability of thiosulphate solutions. Thiosulphate acts as a weak reducing agent, which may consume the oxygen or other mild oxidant and decompose to tetrathionate. The oxidation of thiosulphate is rapid in neutral and acidic solutions. Thiosulphate can be decomposed by many oxidants. The main oxidants in gold leaching are dissolved oxygen, cupric ions and the solid oxidants associated with the ores.

2.3.2 Thiosulphate Decomposition Reactions

When there is no metal ion, thiosulphate tends to degrade slowly by oxygen and form sulphate as a final product. (Latimer, 1952)

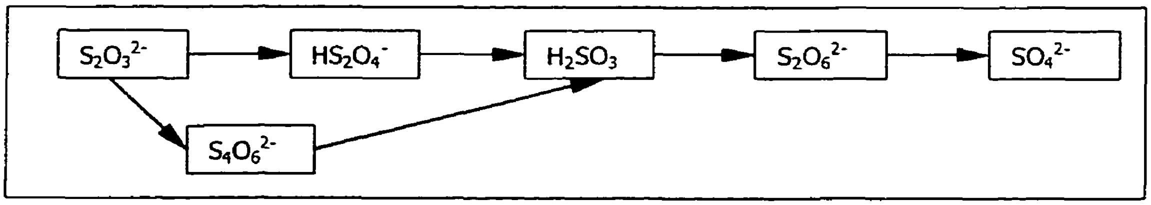

Figure 2-11 Oxidation Route of Thiosulphate in Acidic Solutions

Figure 2-11 shows that, in acidic solution, the direct thiosulphate decomposition products are $HS_2O_4^-$ or tetrathionate. Equations 2-8 and 2-9 explain the generation of tetrathionate and sulphite as the primary and secondary oxidation products.

$$2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 2e^-, E_0 = -0.08 \qquad (2\text{-}8)$$

$$6H_2O + S_4O_6^{2-} \rightarrow 4H_2SO_3 + 2H^+ + 6e^-, E_0 = -0.51 \qquad (2\text{-}9)$$

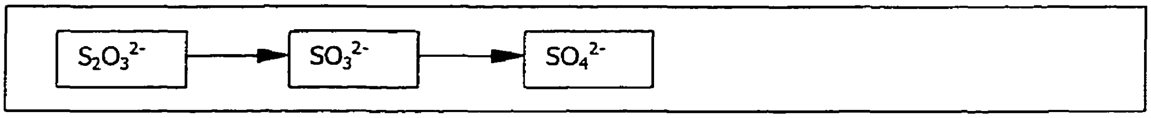

Figure 2-12 Oxidation Route of Thiosulphate in Alkali Solutions

Figure 2-12 shows that, in a basic solution, the direct oxidation product of thiosulphate is sulphite instead of tetrathionate. Equation 2-10 explains the generation of sulphite:

$$S_2O_3^{2-} + 6OH^- \rightarrow 2SO_3^{2-} + 3H_2O + 4e^-, E0 = 0.58 \qquad \textbf{(2-10)}$$

Latimer (1952) concluded that the oxidation of thiosulphate to tetrathionate might be carried out by electrolysis of alkali sulphites. The products of this hydrolysis were claimed to be influenced by the presence of other redox couples, which may be formed either as added catalyst (metal ions) or formed by oxidation of the surfaces of the anodes. As an example, more tetrathionate would be produced in cobalt solution; less tetrathionate would be produced in the presence of molybdate.

Abbruzzese et al. (1995) reported that the thiosulphate decomposition products in a gold leaching process are CuS, sulphate, tetrathionate, sulphite and sulphide anions, as given:

$$S_2O_3^{2-} + Cu^{2+} + H_2O \rightarrow CuS + SO_4^{2-} + OH^- \qquad \textbf{(2-11)}$$

$$H_2O + 0.5O_2 + 2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 2OH^- \qquad \textbf{(2-12)}$$

$$3S_2O_3^{2-} + 3H_2O \rightarrow 4SO_3^{2-} + 2S^{2-} + 6H^+ \qquad \textbf{(2-13)}$$

Cao et al. (1992) suggested a multilevel decomposition as follows:

$$S_2O_3^{2-} + 6OH^- \rightarrow 2SO_3^{2-} + 3H_2O + 4e \qquad \textbf{(2-14)}$$

$$SO_3^{2-} + H_2O \rightarrow SO_4^{2-} + 2e + 2H^+ \qquad \textbf{(2-15)}$$

Through the study of Eh-pH diagrams, Aylmore and (2001) muir claimed that trithionate are the most probable product of thiosulphate (see Figure 2-7) . In an alkaline solution, sulphite can be an intermediate product. Tetrathionate is not stable in the alkali solution. The Eh-pH diagrams also indicate the product of decomposition was affected by the oxygen content and solution pH. At a high oxygen concentration, thiosulphate tends to be converted to trithionate. With a high pH (>9), the primary product of thiosulphate decomposition is sulphite.

2.3.3 Thiosulphate Stability in Gold Leaching

In early stage of thiosulphate gold leaching research, elevated temperatures and oxygen pressures were used to give a better gold extraction. Thiosulphate consumption under such a condition was very high. The products under such a condition are supposed to be sulphite, sulphate, sulphide, precipitated elemental sulphur and precipitated metal sulphide (Tozawa, 1981). The increase of thiosulphate consumption limited the gold extraction and cause the thiosulphate gold leaching process to be very expensive.

After copper amine was recognized as the most effective catalyst, many researchers started to focus on ambient temperature leaching with a longer duration time in order to save on reagent. Copper can also increase the consumption of thiosulphate during the gold leaching process (Zipperian, Raghavan, 1988). Cupric ion may oxidize the thiosulphate to tetrathionate (Tykodi, 1990). The reduction of cupric ion is easily supported by observation in which the characteristic blue color of cupric ion faded and a colourless solution containing the complex ion $Cu_2(S_2O_3)_2^{2-}$ resulted (Equation 2-16 and 2-17). In the presence of oxygen and ammonia in solution, the above complex will be oxidized to cupric tetra amine (Equation 2-18).

$$2S_2O_3^{2-} + 2Cu^{2+} \rightarrow 2Cu^+ + S_4O_6^{2-} \tag{2-16}$$

$$2S_2O_3^{2-} + 2Cu^+ \rightarrow Cu_2(S_2O_3)_2^{2-} \tag{2-17}$$

$$2Cu(S_2O_3)_2^{3-} + 8NH_3 + 0.5O_2 + H_2O \rightarrow 2Cu(NH_3)_4^{2+} + 4S_2O_3^{2-} + 2OH^- \tag{2-18}$$

Usually, higher thiosulphate initial concentrations led to a higher consumption (Zipperian and Raghavan, 1988) (Dhawale, 1993). The reagent strength was reduced to a lower level by several researchers to optimise the gold leaching condition and reduce the thiosulphate consumption. Wan (1994) suggested thiosulphate concentrations should be between 0.1~0.2 M. Marchbank and Thomas (1996) suggested thiosulphate concentrations should be between 0.02~0.1 M.

For the purpose of reducing the thiosulphate consumption, sulphite and sulphate additives were suggested and evaluated by various researchers (see Equations 2-19 to 2-21). They were trying to transform the free sulphide ions into thiosulphate during the leaching process or to slow the decomposition reactions by increasing the concentration of thiosulphate decomposition products. (Hemmati, et al, 1989) (Hu, et al 1991)

$$6H^+ + 2S^{2-} + 4SO_3^{2-} \rightarrow 3H_2O + 3S_2O_3^{2-} \tag{2-19}$$

$$SO_3^{2-} + 2OH^- + S_4O_6^{2-} \rightarrow 2S_2O_3^{2-} + SO_4^{2-} + H_2O \tag{2-20}$$

$$3H_2O + 2S^{2-} + 3SO_3^{2-} \rightarrow 6OH^- + 2S_2O_3^{2-} + S \tag{2-21}$$

Researchers in biological science also studied the bio-degradation of thiosulphate. Elsie Fece de Millano and Earnest F. Gloyna (1981) reported the decomposition of thiosulphate in wastewater treatment activated sludge system.

Dhawale (1993) summarized the factors affecting the stability of thiosulphate as below:

A. The purity of water. Thiosulphate solution prepared in freshly boiled double-distilled or distilled-deionized water is very stable if stored in an airtight bottle.

B. Diluted thiosulphate solution (0.01M or lower) decomposes more rapidly than concentrated solution (0.1M or higher).

C. The presence of certain metals or alloys

D. The presence of certain metal ions and sulphur bacteria

E. Exposure to ultraviolet light.

3. Experimental

3.1 Thiosulphate Solution Decomposition Tests

The method of oxygen supply is very important in this investigation. Both open-vessel method and closed -vessel method were applied in the following solution decomposition tests.

3.1.1 Open-vessel Test Method

The apparatus in the open-vessel tests is a series of plastic bottles connected by tubing as shown in the following sketch (Figure 3-1).

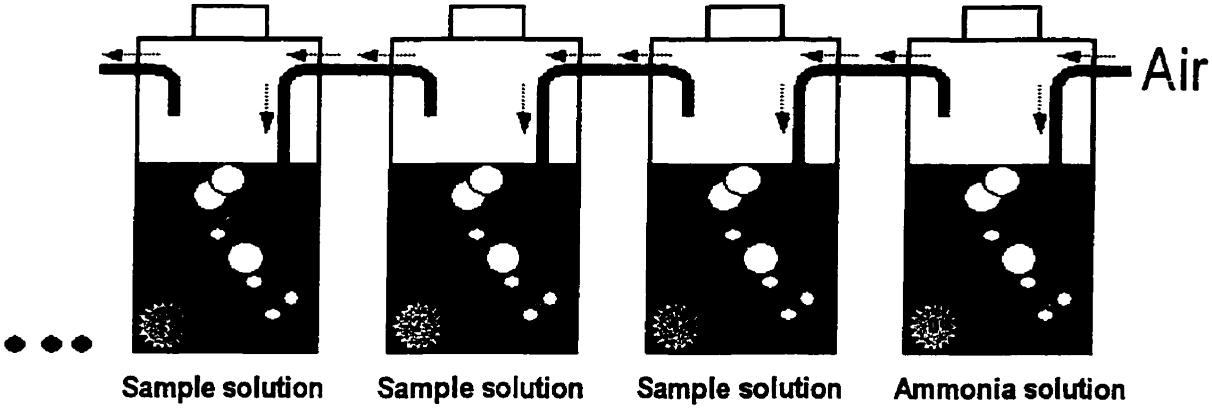

Figure 3-1 Apparatus for Open-Vessel Solution Decomposition Tests

The tests were conducted at ambient temperature and atmospheric pressure. Ammonia saturated air flow were pumped into the connected bottles and flowed out from the last bottle. Ammonia concentration in bottle number 0 was set equal to the following solutions and maintained constantly during the test procedure. Thus, the ammonia concentrations in the following bottles were stable during the test procedure.

There was no air and solution leakage. The airflows in each bottle were the same. The dissolved oxygen in each bottle was also assumed to be the same.

Solutions (500 ml) under different reagent conditions were filled into the bottles. The air bubbles produced on the bottom of the bottles agitated the solutions. The incoming air supplied oxygen continuously. Thiosulphate decomposition tests were carried out over a period of 24 to 48 hours. Titration of reagent concentration was performed to build a decomposition curve for each solution.

3.1.2 Closed-vessel Test Method

The closed-vessel tests were also conducted at ambient temperature and atmosphere pressure. Solutions (50 ml) prepared at the defined conditions were filled into capped glass bottles, which were laid on rollers rotating at a constant speed. The bottles were completely sealed without any air leakage and settled on rolls as shown in the following sketch (Figure 3-2).

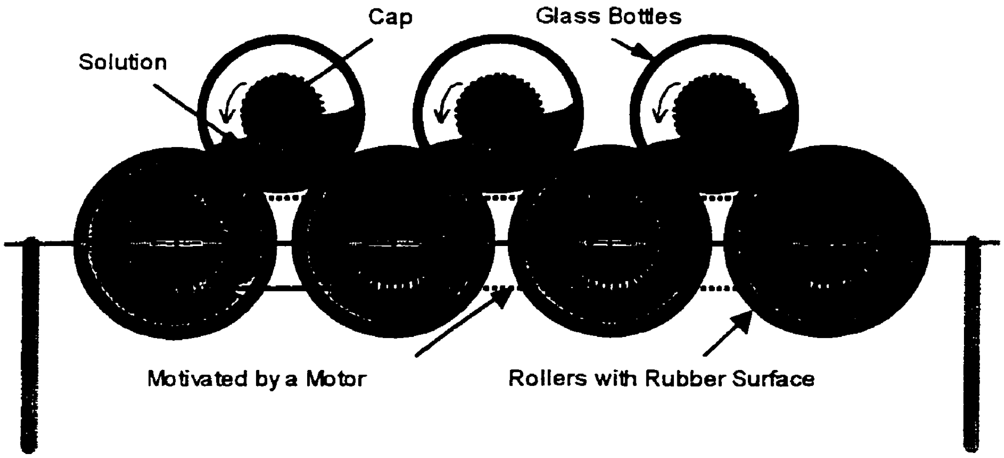

Figure 3-2 Apparatus for Closed-vessel Solution Decomposition Tests

The retention time was 24 hours. Titration and air-replenishment were carried out at the 4th and 24th hour. After 24 hours, zinc powder was added to sample solutions. Another titration was conducted right after zinc precipitation.

3.1.3 Zinc Precipitation Test

Zinc precipitation is a possible gold recovery method. In this stage of the experiment, zinc precipitation was conducted to study the thiosulphate activity and its decomposed products.

The amount of zinc addition is related to the gold and copper recovery from thiosulphate solution. The amount of copper left in the solution after zinc precipitation may affect the gold recovery and thiosulphate stability. When a suitable amount of zinc is added, both gold and copper will be precipitated in less then 5 min. At the same time, thiosulphate is re-generated. The amount of zinc depends on not only the gold content but also on the amount of copper in solution. The color of pregnant solution faded completely when a sufficient amount of zinc was added. The value of the proper zinc quantity depends on the particle size of the zinc powder and stirring strength. In this investigation, 0.36 gram of zinc is normally needed in 50 ml of pregnant solution (with 0.03M copper ion). Excessive addition of zinc will not influence the gold /copper precipitation and thiosulphate re generation results in the first few minutes.

The solution remained in a glass bottle on rolls for 5 minutes. Then, the solution was separated from solid particles by filtration. Titration was carried out for the understanding of the change of pregnant solution.

3.1.4 Analytical Method

In the thiosulphate gold leaching solution, the major sources of sulphur compounds are thiosulphate and sulphide anions dissolved from sulphide minerals. The products of thiosulphate decomposition are sulphite and tetrathionate. The tetrathionate will further convert into thiosulphate and sulphite. These four compound, thiosulphate, sulphite, tetrathionate and sulphide anion are not stable when oxygen exists in solution. The studies on these sulphur compounds are essential to the thiosulphate stability as well as the gold extraction. Due to the instability of those species, the analysis of solution must be done as quickly as possible.

The iodimetric method is one of the simplest analysis methods to analyse reductants in solutions. Thiosulphate will be oxidized and decompose into tetrathionate, which is meta-stable in iodine solution. Sulphite can be oxidized by iodine as well and the product is sulphate. Sulphide will react with iodine to form elemental sulphur precipitation. Thus, iodine titration is a common method for analysing thiosulphate in the gold leaching solution. The procedure of the iodimetric method is explained as follows. (Skoog et al., 1992).

A. Weigh about 40g of KI into a 100ml beaker. Add 12.7 g of iodine and 10ml of water to that beaker. Stir for several minutes. Introduce about 20ml of water and stir until most of the iodine is dissolved. Separate the undissolved KI from the solution.

B. Add about 25 g of $Na_2SO_3.5H_2O$ and 0.1 g of Na_2CO_3. Stir until the solid has dissolved. Stock the solution in a clean glass container in a dark place.

C. Weight about 1 g of soluble starch and 15 ml of water into a paste, Dilute to about 500ml with boiling water and then heat until the mixture is clear. Cool the solution and stock it in a tightly stopped bottle.

D. Determine the concentration of iodine (W) solution accurately by standard sodium thiosulphate solution.

E. Take a 10ml sample (Y) of unknown thiosulphate solution. Adjust the solution pH to 7 with sulphuric acid. Measure and record the vo lume of neutralized thiosulphate solution (V). Transfer the thiosulphate solution to a buret. Introduce 5 ml of iodine solution (X) into a small beaker. Titrate the thiosulphate solution into the beaker until the brown color appears. Add 3 ml of starch solution into the solution. Continue the titration until the dark blue color disappears. Record the volume of consumed thiosulphate solution (U). Calculate the thiosulphate concentration by the following equation.

$$M=(2*W*Y*V)/(U*Y)$$

The problem is how to differentiate these three compounds, thiosulphate, sulphite, and tetrathionate. Adjusted Iodine Titration was developed for the above purpose with several modifications. Dissolved zinc ion was applied to precipitate the sulphide ion and separate it from the other species. Formaldehyde was added to react with sulphite and form a stable compound. Thiosulphate, tetrathionate and sulphide do not react with formaldehyde.

$$Zn^{2+} + S^{2-} \rightarrow ZnS \qquad (3\text{-}1)$$

$$HCOH + HSO_3^- \rightarrow H_2C(OH)SO_3^- \qquad (3\text{-}2)$$

Kurtenacker (1938) mentioned the above two reactions in his outstanding book, which comprise a complete review of the analytical methods for determining the oxygen acids of sulphur and their salts.

Regarding the titration of tetrathionate, no effective analysing method has been found. By reducing tetrathionate back to thiosulphate with some dissolved metal ions such as Fe (III), iodine titration could be applied in tetrathionate analysis. But this method was not useful in thiosulphate solution.

3.2 Gold Leaching Tests

3.2.1 Ore Samples

A. Hope Brookeee ore

A Canadian mild refractory gold ore was mainly used in this study. The grade of this ore is 3.15g/t. The chemical composition of the sample is 0.26% Cu, 4.85% Fe, 4.08% S. 0.20% C (total) and trace amounts of Ag. Mineral identification was performed by means of an image analyzer (MP-SEM-IPS). The quantitative amounts of opaque and gangue minerals are listed as below (Table 3-1).

Table 3-1 Mineralogical Composition of Ore Sample (Hope Brookeee)

Minerals	% Wt.
Pyrite	10.4
Iron Oxide	5.1

Chalcopyrite	0.5
Rutile	0.3
Barite	0.2
Tetrahedrite	0.06
Galena	0.06
Pyrrhotite	Trace
Arsenopyrite	Trace
Quartze, Clay	81.0
Ankerite	2.4

B. "M" ore and "J" ore

To confirm the experimental conditions and results on Hope Brookeee ore, a high-grade, copper bearing sulphide ore named "M" ore was used. A non-copper, high-grade ore sample without sulphide minerals, named as "J" ore was used in some tests to explore the copper sulphate requirement and avoid the influence of copper minerals. The M ore contains 22g/t of gold. There is about 5.5% of Fe, 0.31% of Cu, 2.55% of S and 0.81% of C in M ore. The grade of the J ore is 16.26 g/t. There is about 0.18% of Fe, 0.002% of Cu and 0.19% of C in J ore.

3.2.2 Open-vessel Leaching Tests

The tests were conducted at ambient temperature and atmosphere pressure. Solutions (250ml) prepared according to a defined condition were filled into a capped glass bottle, which was laid on rollers rotating at a constant speed. The bottles were completely sealed without any air leakage. The experiment installation is shown in Figure 3-3.

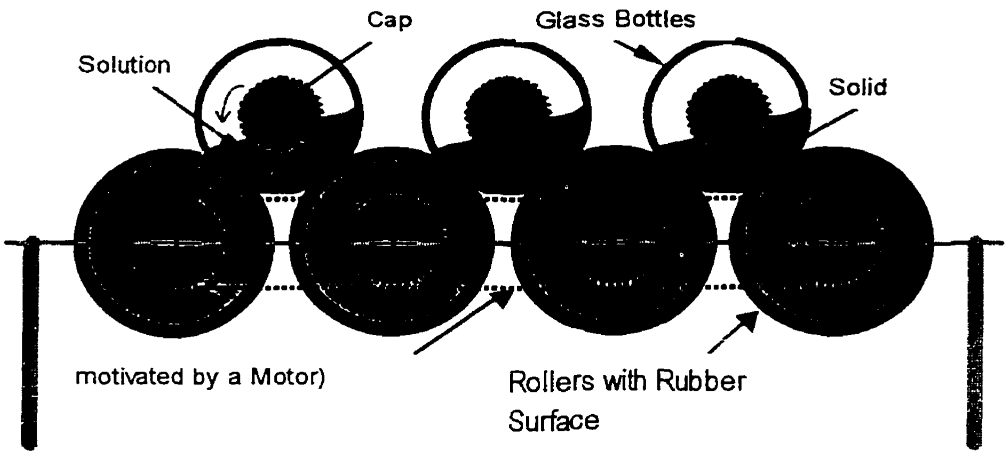

Figure 3-3 Apparatus for Closed-vessel Gold Leaching Tests (Bottle-on-rolls)

Ore samples were grounded in a Denver laboratory-scale rod mill with 13.5 kg of graded rod charge. One kilogram of ore sample was grounded at 65% solids and then pressure filtered. The cake was equally divided into five parts. About 200g samples were pulped with water in a 2-liter glass bottle to 45% solids. Copper sulphate was weighed and dissolved completely in a 100ml flask bottle with water and ammonia solution. Copper sulphate solution and ammonium thiosulphate were filled into the glass bottle. Solution pH was adjusted by sulphuric acid or lime addition. The solution volume was adjusted to 250ml with water. Bottles were sealed and laid on the rollers with a rotating speed at 32rpm. Tests were conducted in groups containing 3 to 10 bottles of samples. Samples in each group were prepared from the same batch of ground ore. Tests in the same group were conducted simultaneously using the same temperature, air humidity and water quality conditions.

After about 4 hours leaching, a small amount of solution was removed for thiosulphate titration. Fresh air was allowed to enter the bottles during the titration process. After titration, the bottles were sealed again and the leaching was carried out for another 20 hours.

At the end of gold leaching tests, one more titration was conducted to measure the final reagent level. Filtration was carried out on a Buchner Vacuum funnel to separate pregnant solution and residue solid. During the filtration process, the ore sample was washed by thiosulphate solution and fresh water separately. The diluted pregnant solution was measured, sampled and filled into a plastic bag with standard acid charge for fire assay. The solid residue was dried, weighed and assayed for gold with a conventional fire assay technique. Zinc precipitation was also conducted on the collected pregnant solution.

3.2.3 Gold Assay

Gold content was measured by the standard fire assay method. Standard flux was prepared by mixing the following reagents.

Litharge	22 parts
Soda ash	7.5 parts
Borax	3.5 parts
Silica	3.5 parts

About 120 grams of flux was mixed with 2.89 grams of flour, a silver ingot and 30 grams of solid sample. The mixture was stirred and then heated in a crucible at 1038 °C for 60 min. The melt was poured into ironmould. The lead button was hammered into a cube and heated in a cupel at 950°C. After all lead disappeared, the gold-silver bead was put into a 10ml flask. The silver was dissolved by 2-3 ml of nitric acid on a hot plate in about 10 minutes. 5 ml of hydrochloride acid was added to dissolve gold. After the bead was completely dissolved, the flask was cooled and filled up to the mark. The value of gold was then determined by atomic adsorption spectrometer at the wavelength of 242.8.

To avoid the interference from copper content in pregnant solution, the solution samples were assayed by fire assay method too. Normally, 50 ml or 100ml of pregnant solution was mixed with 120 grams of standard flux, 2.89 grams of flour, and a silver ingot. The mud was dried at 80°C and then assayed according to the standard fire assay procedure.

3.2.4 Standard Gold Leaching Conditions

The standard leaching condition in this research follows the previous test results on the Hope Brookeee Ore sample. Yen and his research grou p (1996, 1999) did the initial research on this ore sample with both agitation and column methods.

Results of the agitation tests indicate that a solution with 0.5 M ammonium thiosulphate, 0.1M copper sulphate and 6 M ammonia at pH 10.2 could reach a maximum 97% gold extraction in 24 hours. 93% of the particles were finer than 200 -mesh. The column leaching tests reduced the optimum reagent condition down to 0.3 M of thiosulphate, 0.03 M of copper sulphate and 3 M of ammonia at pH 10.2.

In this investigation, 0.3 M ammonium thiosulphate, 0.03 M copper sulphate, 3 M ammonia and pH 10.2 was set as the standard leaching conditions. The quantity of ore sample in bottle was reduced from 1000 grams to 200 grams to enlarge the oxygen supply by increasing the air volume in the bottles. The particle size was set at 85% minus 200 -mesh.

4. Results From Thiosulphate Solution Stability Tests

To explore the decomposition chemistry of thiosulphate and study the effects of variables and additives, thiosulphate solutions were investigated in a series of decomposition tests in the absence of an ore sample. Both open and closed-vessel methods were applied in this experimental stage. Regeneration of thiosulphate in a zinc precipitation process was also investigated. These results were used as evidence to explain the decomposition chemistry, which will be discussed in chapter 6. They were also used to provide the guidance for the gold leaching tests, which will be described in Chapter 5.

4.1 Open-vessel Solution Decomposition Test Results

Open-vessel tests were conducted to explore the effects of variables and additives on the thiosulphate stability. The general testing conditions for open-vessel tests are listed in Table 4-1. Modification of these conditions will be specified in the specific sections.

Table 4-1 Testing Conditions for Open-vessel Decomposition Tests.

Experiment type	: Decomposition Test	Duration time	: 24 hours
Vessel	: Connected plastic bottles	Temperature	: 20~25 °C
Oxygen Supply	: Air Flow, 15ml/min	Reagent Refilling	: No
Stirring Method	: Air Flow	Zinc precipitation	: No
Solution pH	: 10.2	Solution Volume	: 500 ml
Remarks: All the experiments in a test group were conducted simultaneously			

4.1.1 Effect of Airflow Rate

The effect of airflow rate on thiosulphate stability was studied. The range of airflow rate was from varied from 0 to 15ml/min.

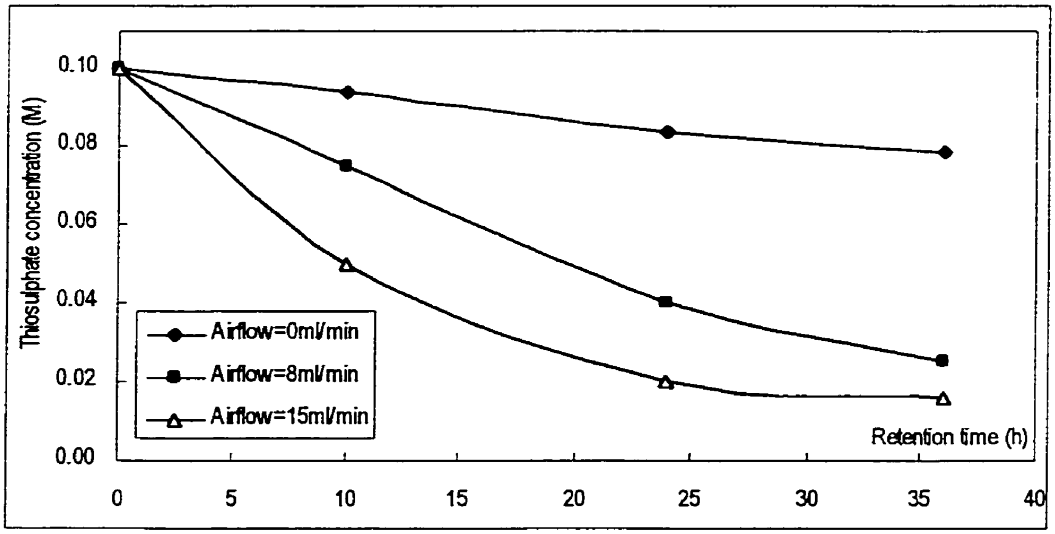

Figure 4-1 Effect of Airflow Rate on Thiosulphate Decomposition Curves
(Thiosulphate 0.1M, Ammonia 3M, Copper sulphate 0.03M, pH 10.2)

Figure 4-1 shows that the thiosulphate concentration was reduced after 36 hours from 0.100M to 0.079M when there was no air supply. Thiosulphate decomposition was 21%. With the introduction of airflow rates at 8 and 15ml/min, the final thiosulphate concentration was reduced to 0.025 and 0.016M respectively. Thiosulphate decomposition was 75% and 84% respectively. Thus, oxygen is one of the most important driving forces causing thiosulphate decomposition. Monitoring the oxygen supply is a possible method for stabilizing the thiosulphate solution.

4.1.2 Effect of Ammonia Concentration

Ammonia acts as a complexing agent in thiosulphate gold leaching. Copper amine produced from the reaction of ammonia and copper acts as a catalyst for the gold extraction reactions. The addition of ammonia might stabilize the copper ammine and reduce the concentration of copper ion and copper thiosulphate complex.

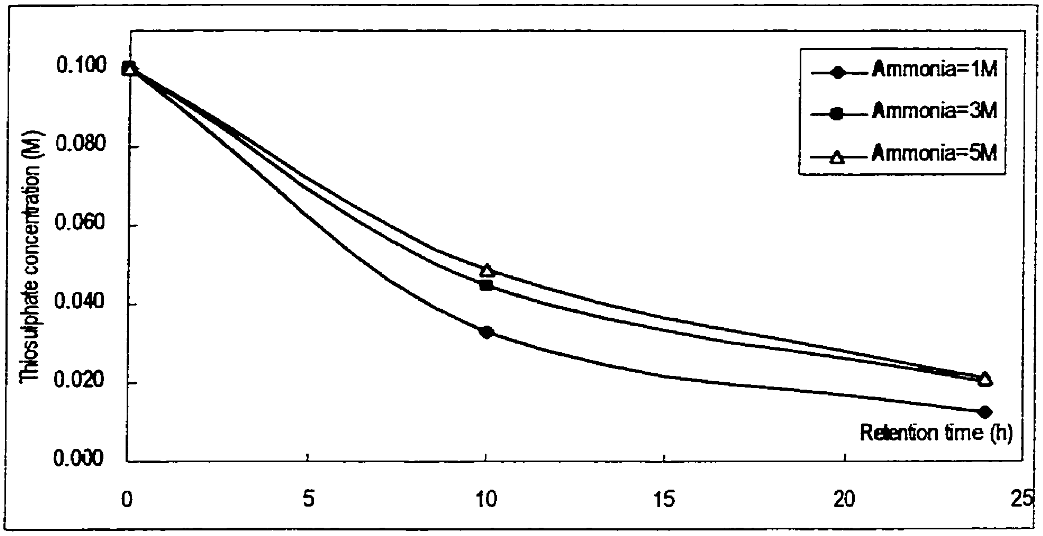

Figure 4-2 Effect of Ammonia Concentration on Thiosulphate Stability

(Solution pH 11, Thiosulphate 0.1M, Copper sulphate 0.03M, Airflow rate 15ml/min)

Figure 4-2 shows that the thiosulphate concentration was reduced from 0.1M to 0.013M after 24 hours with 1M of ammonia. Thiosulphate decomposition was 88%. With the increase of ammonia concentration form 1M to 3M and 5M, the final thiosulphate concentration was increased to 0.02 and 0.021M respectively. The thiosulphate decomposition was 80% and 79% respectively. The improvement on thiosulphate stability by increasing ammonia concentration from 3 to 5M is not significant. Thus, the optimum ammonia concentration is fitted at 3M.

4.1.3 Effect of Solution pH

As shown in the Eh-pH diagrams in Chapter 3, copper tetra amine is stable over a wide range of pH if the solution concentration is high. The pH range for the stable copper tetra amine is narrower when the solution concentration is low. The optimum pH range for the stable copper tetra amine is also the optimum condition for the gold extraction.

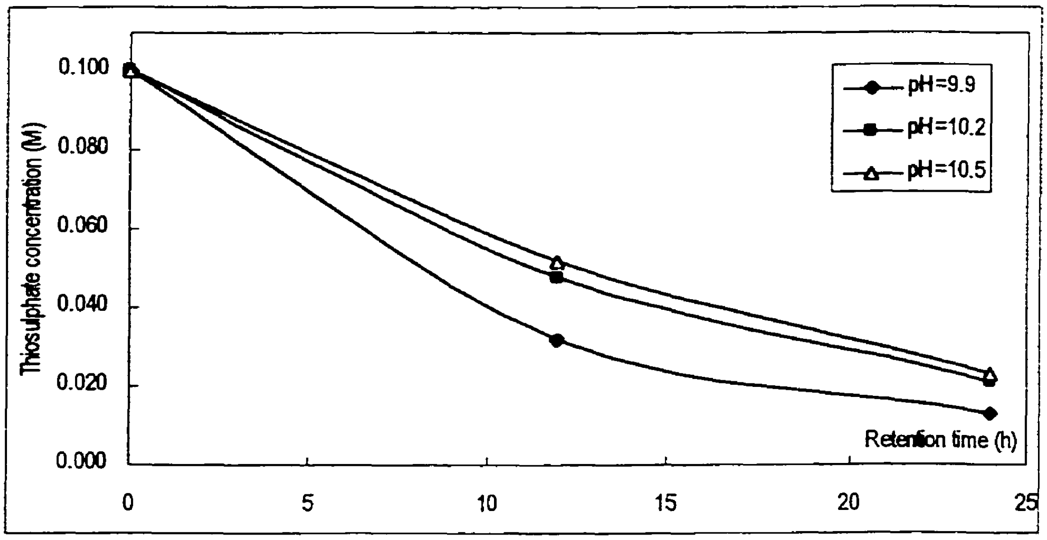

Figure 4-3 Effect of Solution pH on Thiosulphate Decomposition Curves
(Thiosulphate 0.1M, Ammonia 3M, Copper sulphate 0.03M, Airflow rate 15ml/min)

Figure 4-3 shows that 0.1M thiosulphate at the initial stage was reduced to 0.013M after 24 hours at pH 9.9. Thiosulphate decomposition was 87%. As pH 10.2 and 10.5, the thiosulphate final concentration was increased to 0.021 and 0.023M. The thiosulphate decomposition was 79% and 77% respectively.

4.1.4 Effect of Initial Thiosulphate Concentration

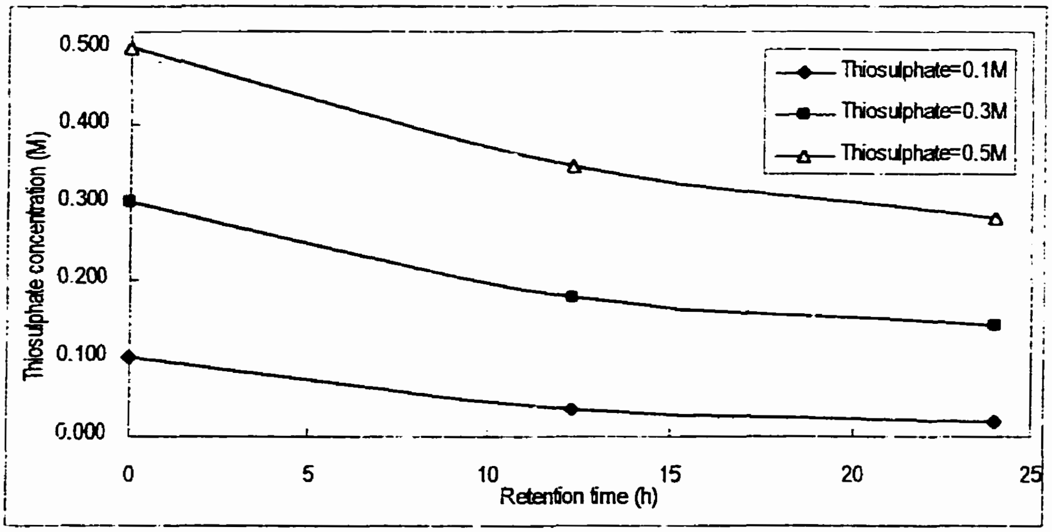

Figure 4-4 Effect of Thiosulphate Initial Concentration on Decomposition Curves
(Airflow-rate 16.8ml/min, Copper sulphate 0.03M, Ammonia 3M, pH 10.2)

Figure 4-4 shows that the stability of thiosulphate increased with its initial concentration. The initial concentration of 0.1M thiosulphate was reduced to 0.018M with 82% consumption after 24 hours. When the thiosulphate initial concentration was 0.3M and 0.5M, the final concentrations were 0.14M and 0.28M with 53.3% and 44.0% consumption respectively.

4.1.5 Effect of Copper Sulphate

Effect of copper sulphate concentration on the thiosulphate stability is shown in Figure 4-5.

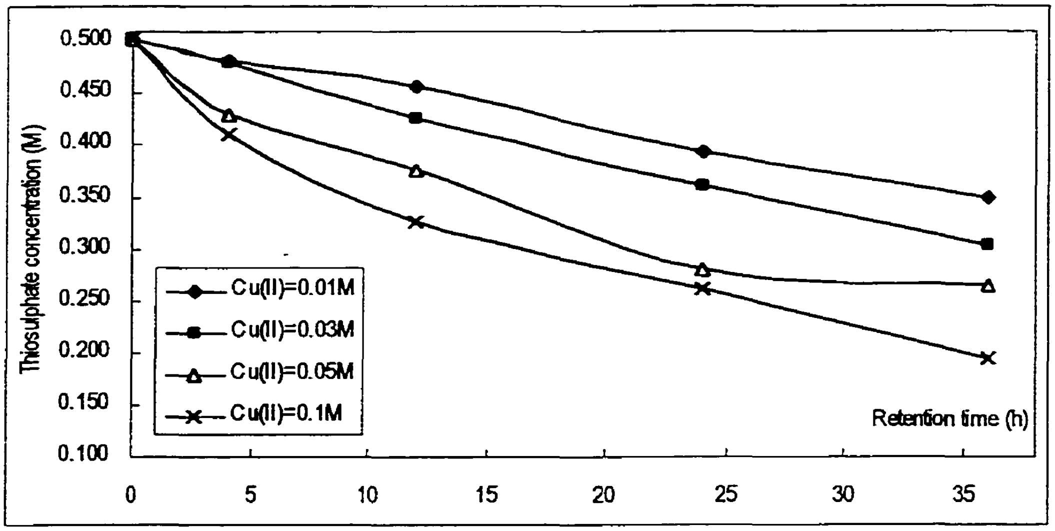

Figure 4-5 Effect of Copper Sulphate Concentration on Thiosulphate Decomposition Curves

(Thiosulphate 0.5M, Ammonia 3M)

The results indicate that, with more copper sulphate addition, the thiosulphate solution become unstable. In a 0.5M thiosulphate solution, the final concentration was only 0.152M with 0.1M of copper sulphate after 48 hours. Thiosulphate consumption was 69.7%. By reducing the copper sulphate concentration to 0.05M, 0.03M and 0.01M, the final thiosulphate concentrations were increased to 0.215M, 0.2867M and 0.331M respectively. The consumption of thiosulphate was reduced from 69.73% down to 58.10%, 42.83%, and 34.06% respectively.

4.1.6 Effect of Various Additives

As mentioned in Chapter 3, the addition of sulphite, sulphate and amino acid were used in previous research as stabilizers for thiosulphate solution. However, there was no universal conclusion concerning these additives. For the purpose of confirmation, they were also used in this investigation. The results in Section 4.1.5 indicated that copper ion is a major species causing the thiosulphate decomposition. For reducing the effect of copper ion on the thiosulphate stability, EDTA, as a strong chelating agent, was used in this study to compare with other additives.

4.1.6.1 Effect of Sodium Sulphite

In this group of tests, the effect of sulphite was studied in the concentration range from 0.005 to 0.05M.

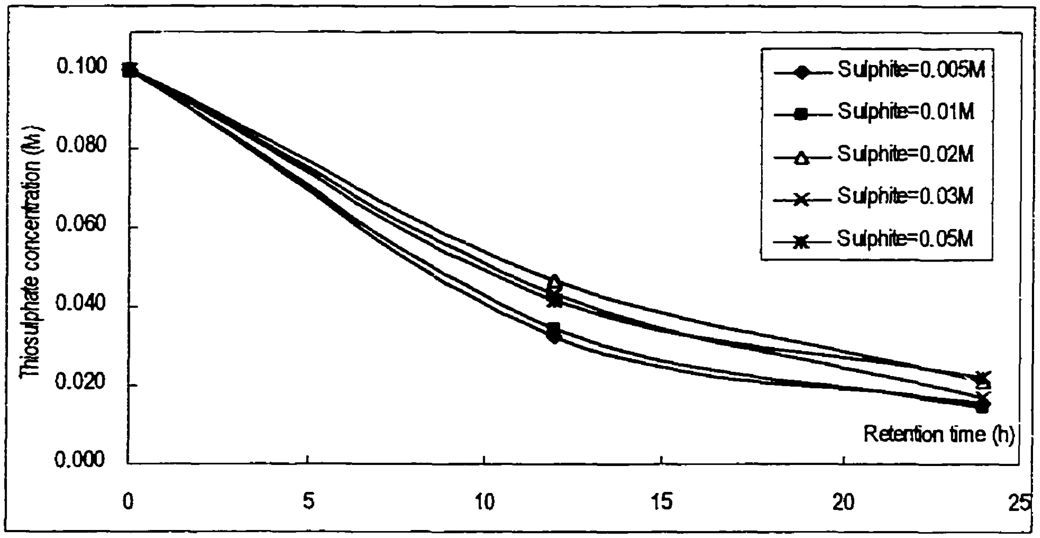

Figure 4-6 Effect of Sodium Sulphite Concentrations on Thiosulphate Decomposition Curves

(Thiosulphate 0.1M, Copper sulphate 0.03M, Ammonia 3M, pH 10.2, Airflow rate 15ml/min)

Figure 4-6 shows that sulphite at a concentration of 0.005M to 0.05M improved the thiosulphate stability in a narrow range. By adding very small amount of sulphite (0.005M), the thiosulphate concentration was reduced from 0.1 to 0.015M with 85%

consumption within 24 hours. The increase of sulphite concentration from 0.005 to 0.05M reduced the thiosulphate consumption by 7%. The thiosulphate final concentration was 0.022M with 0.05M of sulphite.

The slight improvement on thiosulphate stability may be due to the decomposition of sulphite in the presence of oxygen.

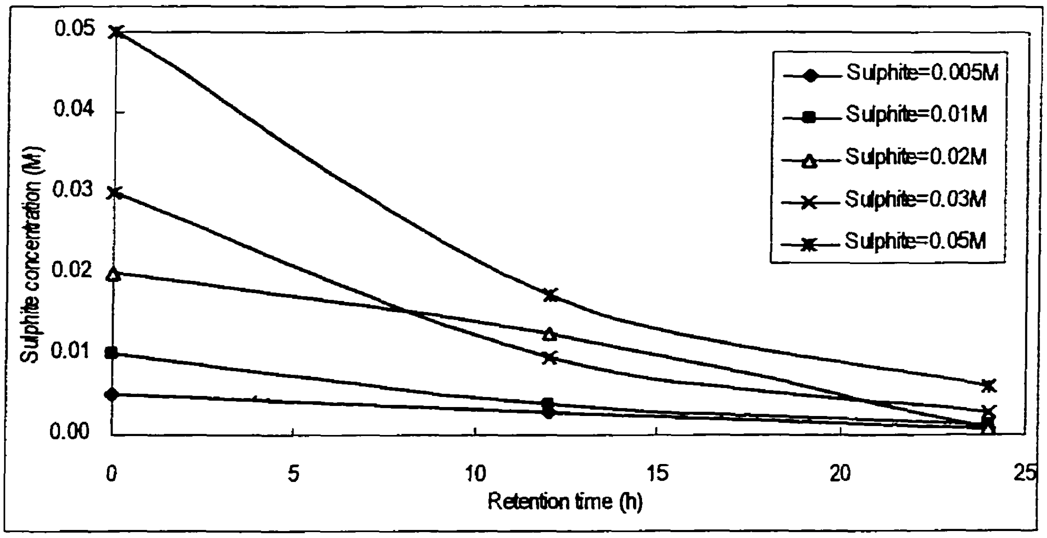

Figure 4-7 Sulphite Decomposition Curves in Thiosulphate Solution.
(Thiosulphate 0.1M, Copper sulphate 0.03M, Ammonia 3M, pH 10.2, Airflow rate 15ml/min)

Figure 4-7 shows the decomposition of sulphite in water solution. Sulphite concentrations at all levels were reduced to a very low level. 88% of sulphite was lost in 24 hour when the initial concentration was 0.05M. The sulphite decomposition in other solutions ranged from 85% to 96%. The final concentrations were in the range of 0.001 to 0.006M.

4.1.6.2 Effect of Sodium Sulphate

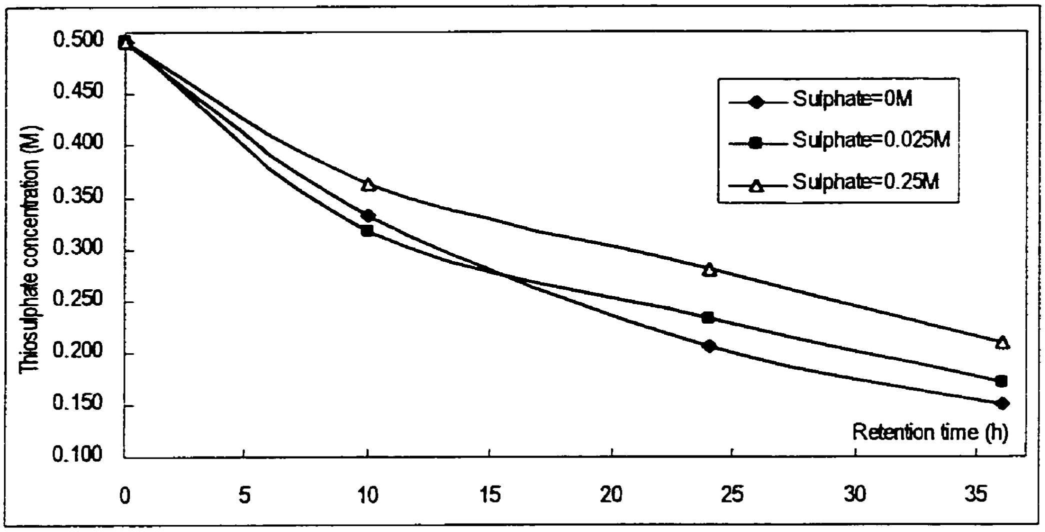

Figure 4-8 Effect of Sodium Sulphate Concentration on Thiosulphate Decomposition Curves

(Thiosulphate 0.5M, Copper sulphate 0.03M, Ammonia 3M, pH 10.2, Airflow 15ml/min)

Figure 4-8 shows the effect of sulphate on the thiosulphate stability. By adding 0.025M of sulphate, the thiosulphate final concentration was increased from 0.15M to 0.17M. The thiosulphate consumption was reduced from 70% to 66%. When the sulphite addition was 0.25M, the consumption of thiosulphate was reduced to 58% in 36 hours. The improvement of sulphate could be due to the fact that sulphate is the final stable product of thiosulphate decomposition.

4.1.6.3 Effect of Amino Acid (Glycine)

Glycine is a simple amino acid, which might complex with copper ion. The concentrations of 0.03M and 0.05M of glycine have been added into the 0.1M thiosulphate solution.

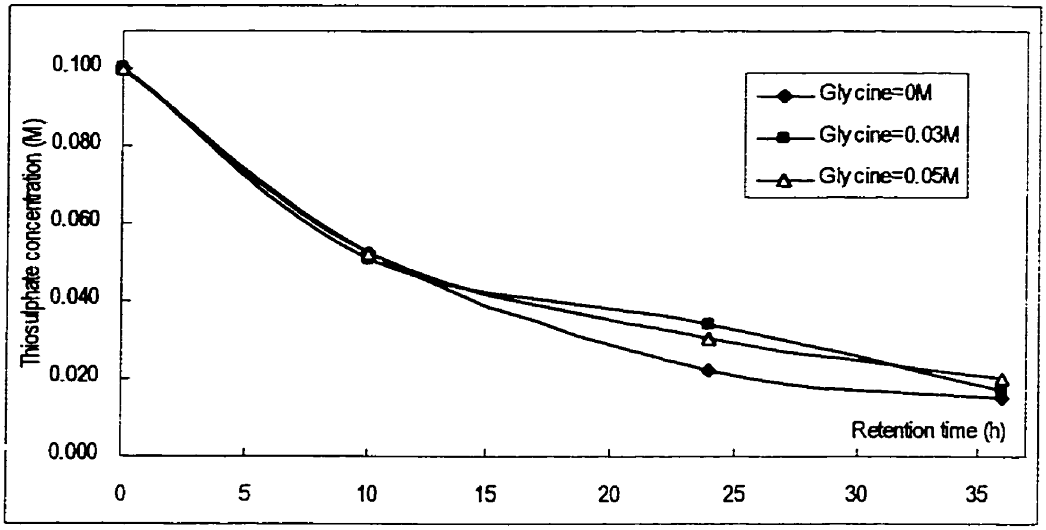

Figure 4-9 Effect of Glycine on Thiosulphate Decomposition Curves
(Thiosulphate 0.1M, Copper sulphate 0.03M, Ammonia 3M, pH 10.2, Airflow rate 15ml/min)

Figure 4-9 shows there was no significant improvement on thiosulphate stability within 36 hours. After 36 hours, 85% of thiosulphate was consumed in the solution without amino acid addition. The thiosulphate consumption was reduced by 5% by adding 0.05M of glycine.

4.1.6.4 Effect of Chelating Agent (EDTA)

EDTA is one of the best chelating agents with copper and may prevent the complexing of copper with thiosulphate.

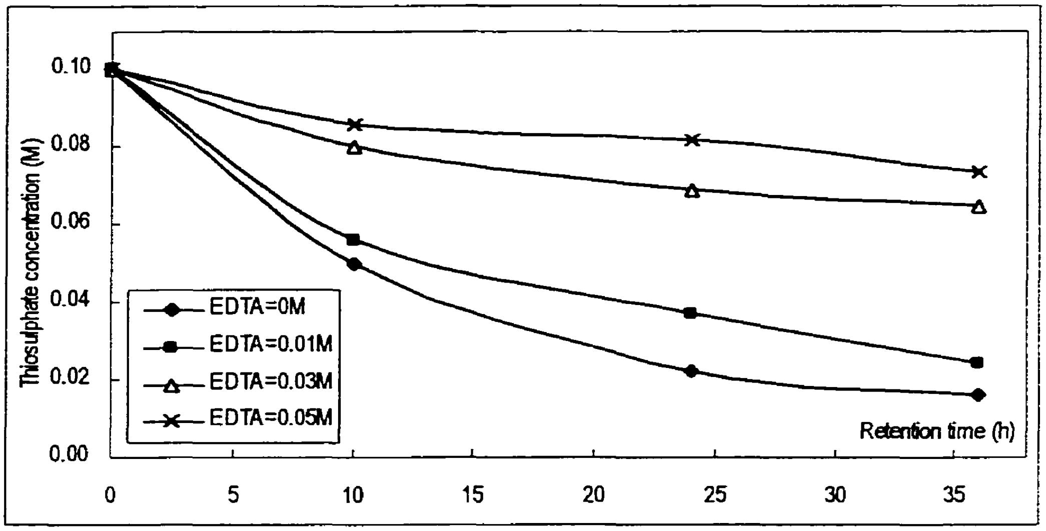

Figure 4-10 Effect of EDTA on Thiosulphate Decomposition Curves

(Thiosulphate 0.1M, Copper sulphate 0.03M, Ammonia 3M)

Figure 4-10 shows the remarkable improvements on thiosulphate stability that occurred by adding EDTA. Without EDTA, the thiosulphate concentration was reduced from 0.1M to 0.016M in 36 hours with a consumption of 84%. With insufficient amount of EDTA addition (0.01M), the final thiosulphate concentration was 0.024M and the consumption of thiosulphate was reduced by 8%. When the concentration of EDTA was 0.03M, which was equal to the concentration of copper sulphate, the thiosulphate concentration was 0.065M and 35% of thiosulphate was consumed. The excessive addition of EDTA (0.05M), increases the thiosulphate final concentration to 0.073M and reduced the thiosulphate consumption to 27% in 36 hours.

The results indicate that EDTA is a potential effective additive. The increase of EDTA concentration leads to a better stability. The effective amount of EDTA should be related to the concentration of copper ion.

4.1.6.5 A Comparison of Various Additives

The effects of various additives were compared in this group of tests.

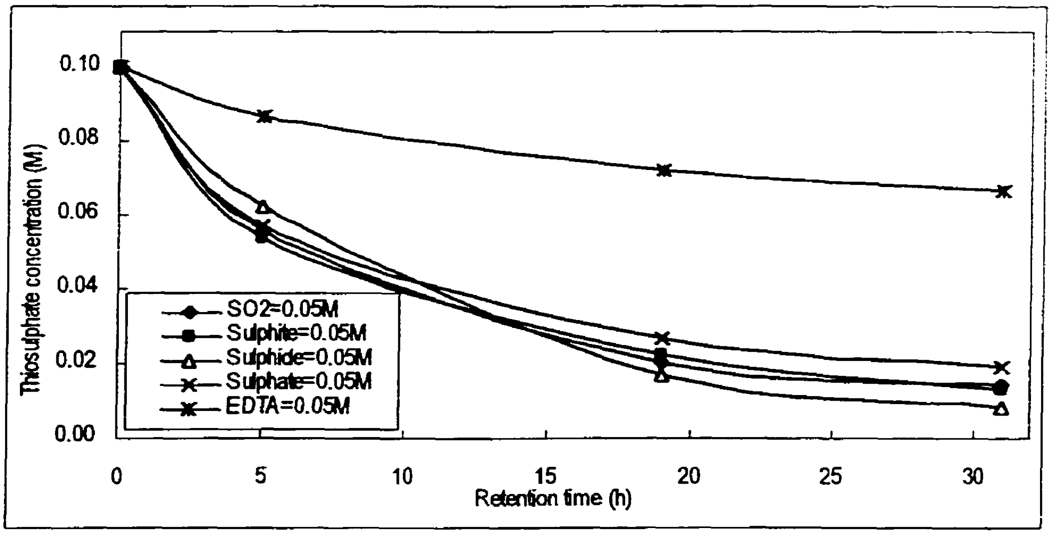

Figure 4-11 Effect of Various Additives on Thiosulphate Decomposition Curves
(Thiosulphate 0.1M, Copper sulphate 0.03M, Ammonia 3M, pH 10.2, Airflow rate 15ml/min)

Figure 4-11 shows the remarkable advantages of EDTA as compared with other additives at the same concentration. In 31 hours, the thiosulphate concentration was reduced from 0.1M to 0.067M with EDTA addition. The thiosulphate consumption was 33%. The thiosulphate concentration reduced from 0.1M to 0.019M ~ 0.002M with other additives and the thiosulphate consumption was 81% to 92%.

The results demonstrate that the chelating action of EDTA with copper ion did greatly improve the stability of thiosulphate in the solution. The improvement by sulphur compound additions was not significant.

4.2 Close-vessel Solution Decomposition Test Results

In a closed-vessel, the dissolution of oxygen into the solution is limited. Thus, less thiosulphate consumption is expected. Thus the stability of thiosulphate in a closed-vessel was studied.

Again, the results of the closed-vessel test can be lead to a better understanding of the thiosulphate decomposition chemistry, the products of reaction and the catalysis function of the copper species.

In this series of experiments, zinc powder was added into the solution after thiosulphate oxidation. The thiosulphate regeneration from the zinc powder gave a better understanding of the characteristics of thiosulphate and its oxidation products. The thiosulphate concentration and sulphite concentration were measured before and after zinc precipitation. The general operating conditions are listed in the following table (Table 4-2). The changes of the conditions will be specified in each test.

Table 4-2 Operating Conditions for Closed-vessel Solution Decomposition Tests

Experiment type	: solution decomposition test	Duration time	: 24 hours
Vessel	: 275 ml, capped glass bottle	Temperature	: 20~25 °C
Oxygen Supply	: air in capped bottles	Reagent Refilling	: no
Stirring Method	: rotating at 114.0 rmp	Zinc Precipitation	: yes
Solution Volume	: 50 ml	ZnPP Time	: 5 min
Oxygen Maintenance	: air-refill at the 4th hour	Zinc Amount	: 7.2g/L
Solution pH	: 10.2		
Remarks: All the experiments in each group were conducted simultaneously			

4.2.1 Effect of Air Supply Method

Both open-vessel and closed-vessel tests were used to compare the stability of thiosulphate in solution (see Figure 4-12).

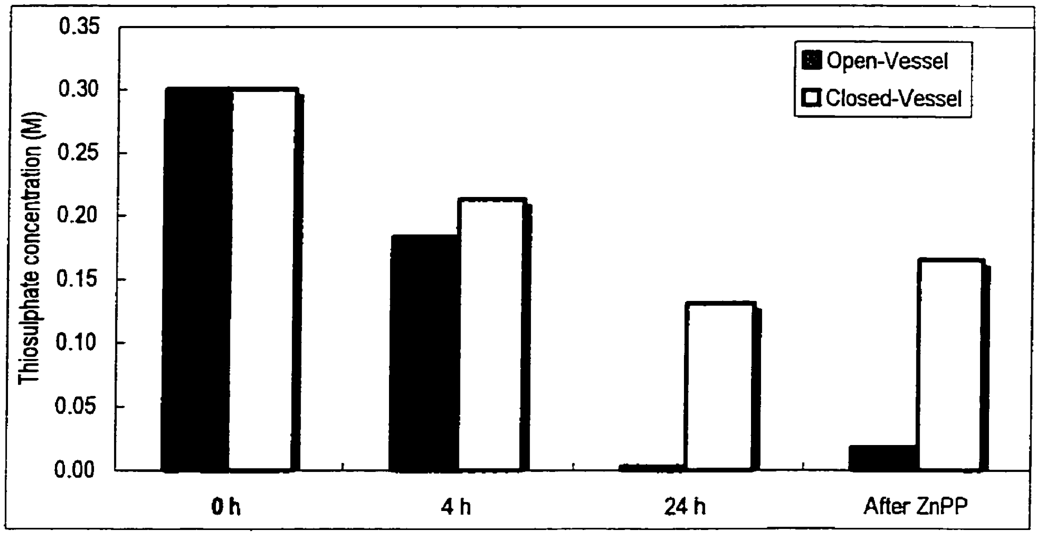

Figure 4-12 Effect of Air Supply Methods on Thiosulphate Concentrations at Each Stage

(Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M, Bottle volume 2520ml, Solution volume 250ml, Bottle rotating speed 59.5RPM)

Figure 4-12 shows that, in open bottle, thiosulphate concentration at the 24th hour was reduced from 0.3M to 0.003M, and 99% of thiosulphate was decomposed. Zinc precipitation increased the thiosulphate concentration to 0.018M. 5% of thiosulphate was restored. In the capped bottle, there was 0.13M thiosulphate left at the 24th hour. 56.5% of thiosulphate was decomposed. After a 5min zinc precipitation operation, the thiosulphate concentration increased to 0.17M, while 11.5% of thiosulphate was restored.

The results indicate that oxygen is one of the initial driving forces of thiosulphate oxidations. For finding the products of thiosulphate decomposition, the solution was not only assayed for thiosulphate but was also measured for sulphite concentration. Identification of tetrathionate was not attempted due to its complexity.

4.2.2 Effect of Solution pH in Closed-vessel

The ammonia concentration in all solutions was 0.3M and their pH was 9.5. The sulphuric acid was used to decrease pH to 9.1. Sodium hydroxide was used to adjust solution pH to 9.9, 10.2 and 10.5.

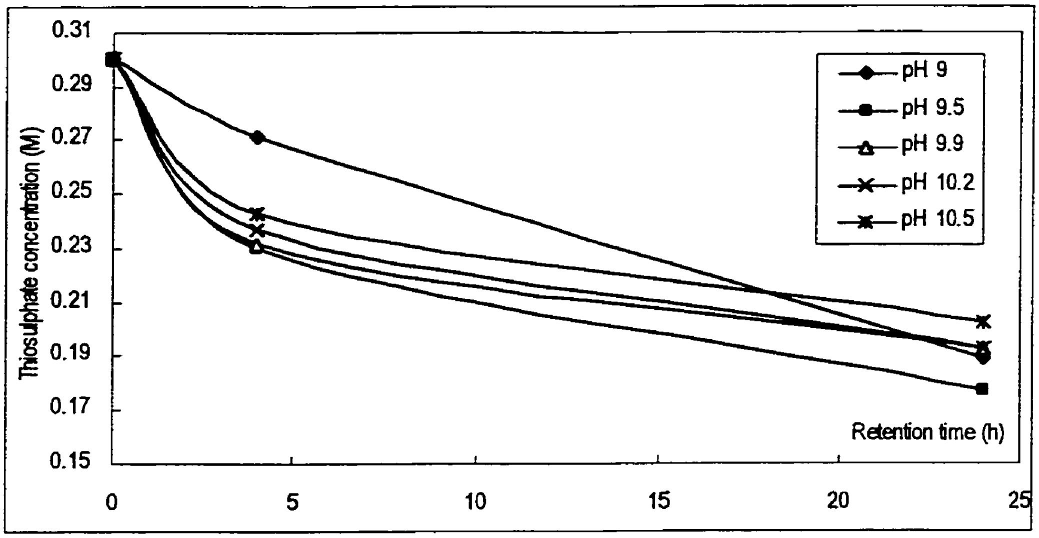

Figure 4-13 Effect of Solution pH on Thiosulphate Decomposition Curves
(Thiosulphate 0.3M, copper sulphate 0.01M, Ammonia 0.3M)

Figure 4-13 shows that thiosulphate at pH 9.3 was more stable in the initial 4 hours. After 24 hours, 37% of the thiosulphate was consumed. Thiosulphate decomposition reached 41% at a solution pH of 9.5. The best result was from the solution with a pH at 10.5 with only 33% consumption.

4.2.3 Effect of Copper Ion

In the open-vessel section, the evidence has indicated that copper ion is one of the reasons for the rapid decomposition of thiosulphate. Adding chelating agent (EDTA) may chelate the copper ion and greatly reduce the decomposition of thiosulphate. In this section of the closed-vessel study, the effect of copper, EDTA and zinc on the decomposition of thiosulphate, sulphite and tetrathionate will be investigated.

4.2.3.1 Thiosulphate Decomposition Tests

In this test group, the effects of copper concentration and the addition of EDTA on the thiosulphate stability were studied under limited oxygen supply conditions.

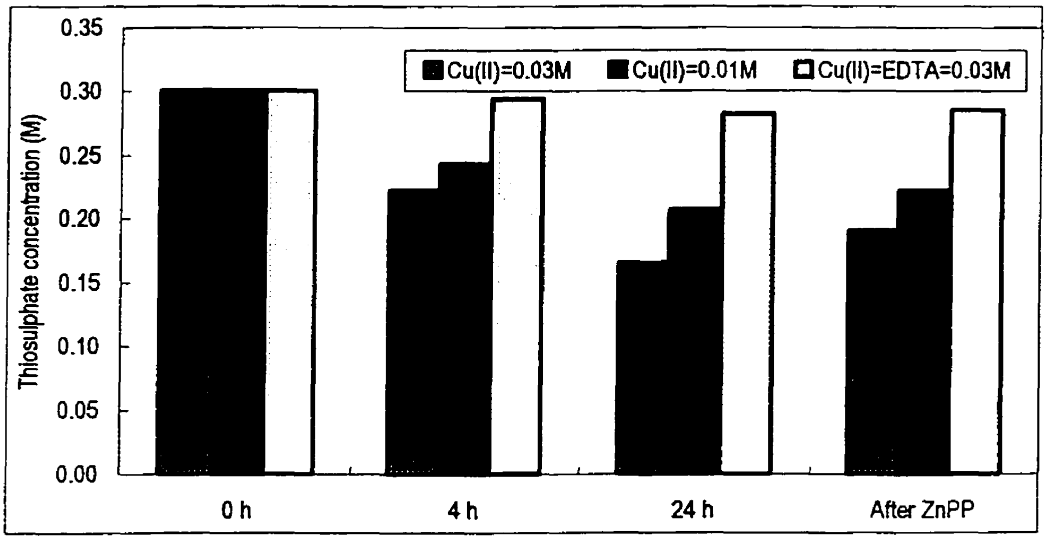

Figure 4-14 Effect of Copper Ions on Thiosulphate Concentrations at Each Stage
(Thiosulphate 0.3M, Ammonia 3M)

Figures 4-14 shows that in the presence of 0.03M of cupric ion, the thiosulphate concentration was reduced from 0.3M to 0.165M after 24 hours and restored to 0.190M by the zinc precipitation operation. 45% of thiosulphate was consumed in 24hours and 8.5% of thiosulphate was restored by zinc precipitation. As the copper sulphate concentration was reduced to 0.01M, the thiosulphate concentration in the 24th hour and after zinc precipitation was 0.207M with 37% of thiosulphate consumption. After zinc precipitation, thiosulphate concentration was up to 0.222M with a 5% of increase. EDTA addition to a 0.03M copper sulphate solution brought the thiosulphate concentration to 0.282M at the 24th hour. The thiosulphate decomposition was only 6%.

4.2.3.2 Tetrathionate Decomposition Tests

The results of the previous section demonstrated that the decomposition of thiosulphate produced both sulphite and tetrathionate. Again, tetrathionate was not stable and might be further converted to sulphite and thiosulphate. In this series of tests, the effects of copper concentration and EDTA on the dissociation of tetrathionate were studied.

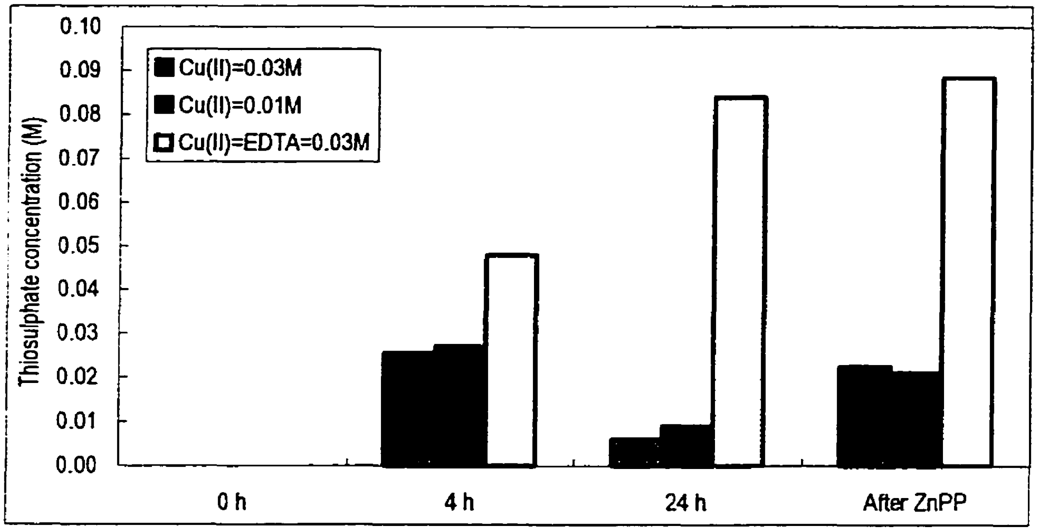

Figure 4-15 Effect of Copper Ion on Thiosulphate Generation in Tetrathionate Solution at Each Stage

(Tetrathionate 0.075M, Ammonia 3M)

Figures 4-15 shows that in solutions with 0.01 and 0.03M of copper sulphate, the generations of thiosulphate were about the same. The thiosulphate concentration was about 0.008M and 0.022M before and after the zinc precipitation. The addition of EDTA increased the amount of thiosulphate to 0.048M at the 4th hour, 0.084M at the 24th hour and 0.088M after zinc precipitation.

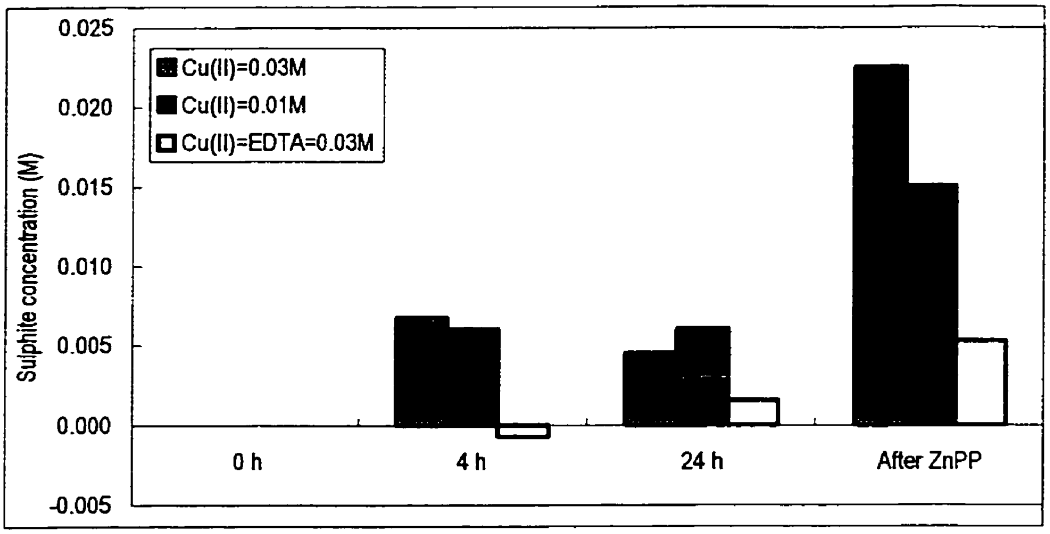

Figure 4-16 Effect of Copper Ion on Sulphite Concentration in Tetrathionate Solution at Each Stage

(Tetrathionate 0.075M, Ammonia 3M)

Figure 4-16 shows that sulphite was generated in the tetrathionate solutions. At the 4th hour, about 0.007M of sulphite was generated in the tetrathionate solutions without EDTA. At the 24th hour, the sulphite concentration was reduced to 0.004 and 0.006M respectively in the 0.03M and 0.01M copper sulphate solutions. After zinc precipitation, sulphite concentrations were increased to 0.022 and 0.015M, as there was 0.03M and 0.01M of copper ion in solutions.

There was no sulphite produced at the 4th hour in the solution with 0.03M of EDTA. At the 24th hour, the sulphite concentration is 0.001M. It is increased to 0.004M after zinc precipitation.

4.2.3.3 Sulphite Decomposition Tests

Sulphite was looked as the secondary product in thiosulphate multi-level oxidation reaction. Thiosulphate decomposed to sulphite through an intermediate product, tetrathionate. The presence of copper enhanced the decomposition of both thiosulphate and tetrathionate. In this series of tests, the effects of copper concentration and the addition of EDTA were studied.

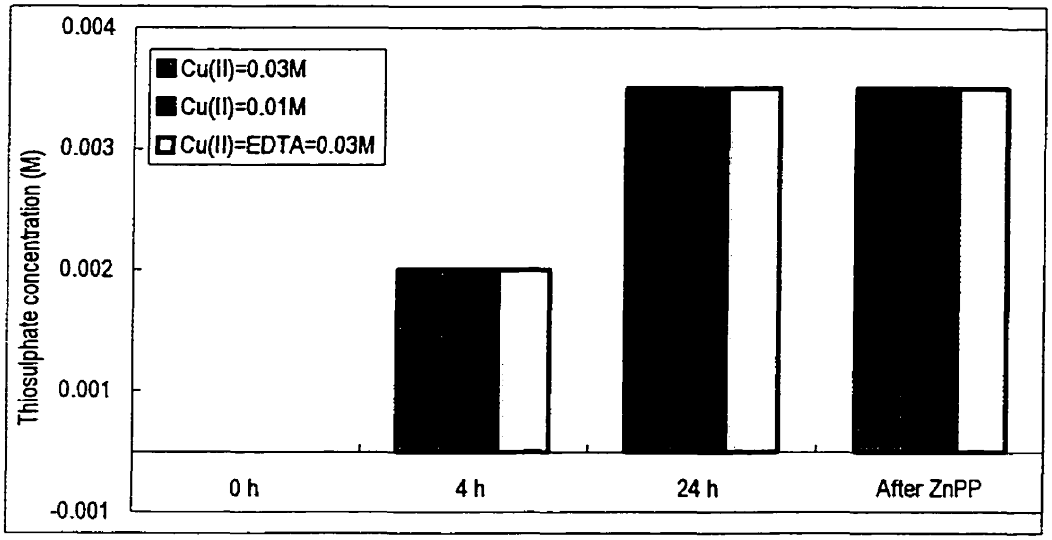

Figure 4-17 Effect Of Copper Ions on Thiosulphate Generation in Sulphite Solution at Each Stage

(Sodium sulphite 0.3M, Ammonia 3M)

Figure 4-17 shows the generation of thiosulphate from a solution containing 0.3M of sulphite. Results were all the same for the solutions containing different amount of copper and EDTA. At the 4th hour, there was 0.0015M of thiosulphate in the solutions. It was increased to 0.003M at the 24th hour. Zinc precipitation did not change the thiosulphate concentration.

The above results indicate that the regeneration of thiosulphate by zinc precipitation is not the result of sulphite decomposition. The presence of copper has a slight effect on the conversion of sulphite to thiosulphate.

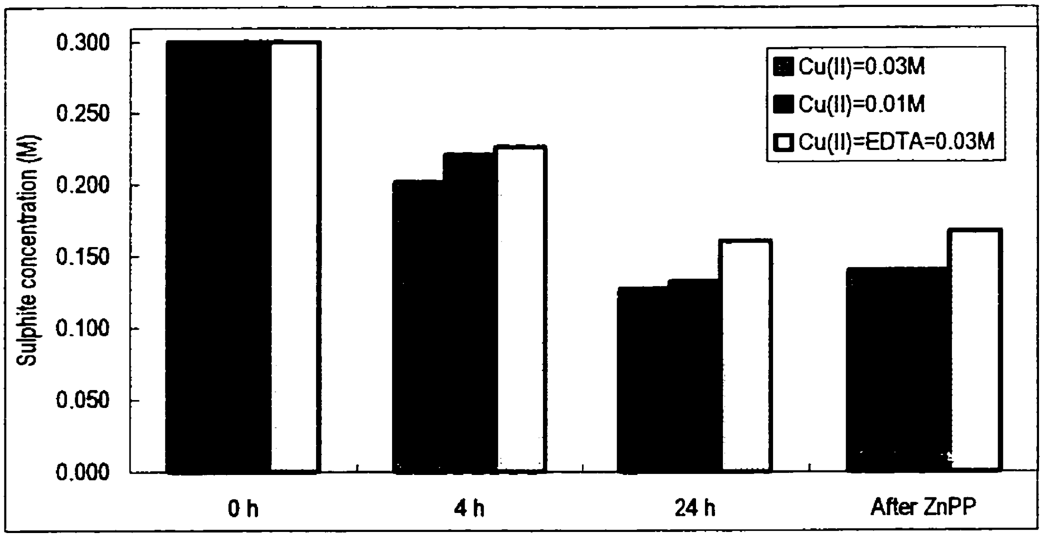

Figure 4-18 Effect of Copper Ion on Sulphite Concentration at Each Stage

(Sodium sulphite 0.3M, Ammonia 3M)

Figure 4-18 shows that, in the solution with 0.03M of copper and EDTA, there was 0.16M of sulphite left at the 24th hour. 46.5% of sulphite was decomposed. In the solutions without EDTA, there was only 0.132M of sulphite left after 24 hours. About 57% of sulphite was decomposed. There was no significant change of sulphite concentration with zinc precipitation.

The above results indicate that the decomposition of sulphite produce a small amount of thiosulphate. The largest portion of sulphite may decompose to sulphate, which is the final stable product.

4.2.4 Effect of Alternative Metal Ions

The presence of copper has demonstrated a strong effect on the decomposition of thiosulphate, tetrathionate and sulphite. It can be concluded that tetrathionate is the first oxidation product in the multi-level decomposition process of thiosulphate. The oxidation of tetrathionate generates sulphite. The final product is sulphate.

For reducing the extent of thiosulphate decomposition, other metal ions, such as nickel and cobalt, were chosen to replace the copper. The effect of nickel and cobalt on the decomposition of thiosulphate, tetrathionate and sulphite are discussed in the following section.

4.2.4.1 Thiosulphate Decomposition Tests

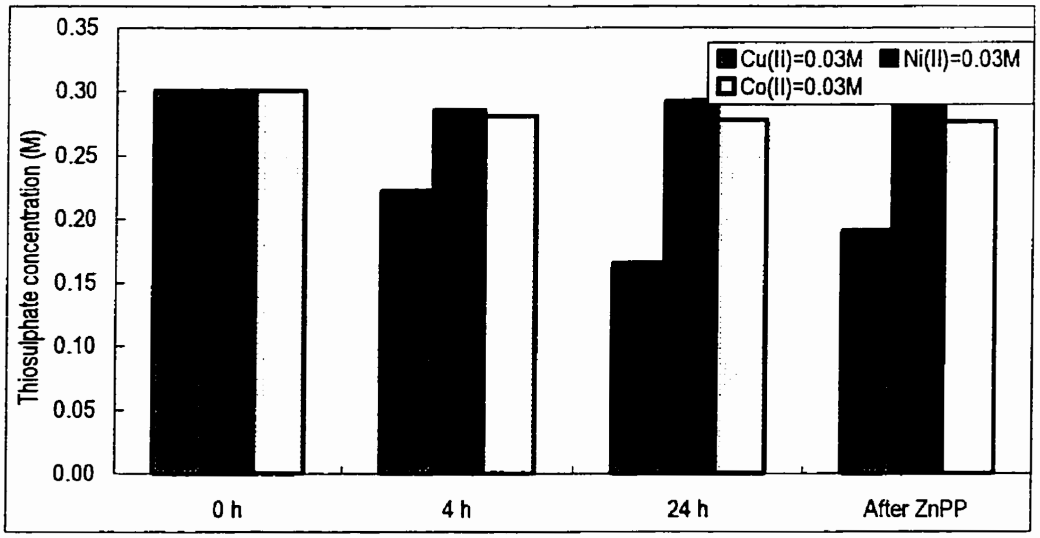

Figure 4-19 Effect of Various Metals Ions on Decomposition of Thiosulphate
(Thiosulphate 0.3M, Ammonia 3M)

Figure 4-19 shows that the most stable solution is the one which contains nickel ion. In the 24th hour, the concentration of thiosulphate in the copper solution was reduced to 0.165M with 45% of decomposition. After zinc precipitation, the thiosulphate concentration was 0.190M and 8.3% of thiosulphate was restored in the copper solution. The decomposition of thiosulphate in the presence of nickel and cobalt was not significant. The final concentration of thiosulphate was 0.267M and 0.292M respectively in the presence of cobalt and nickel. The thiosulphate decomposition was 2.6% and 8% respectively.

4.2.4.2 Tetrathionate Decomposition Tests

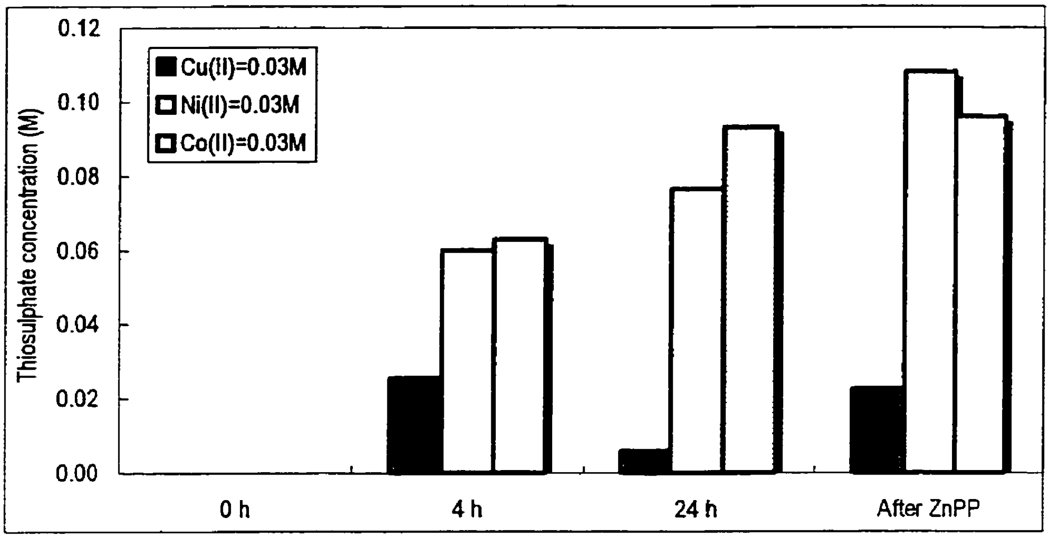

Figure 4-20 Effect of Various Metal Ions on Thiosulphate Generation in Tetrathionate Solution

(Tetrathionate 0.075M, Ammonia 3M, Metal ion 0.03M)

Figure 4-20 shows that the effect of copper, nickel and cobalt on the stability of tetrathionate in a concentration of 0.075M. At the 4th hour, 0.026M of thiosulphate was generated in the presence of 0.03M of copper. However, the thiosulphate concentration was reduced to 0.005M at the 24th hour. After zinc precipitation, the thiosulphate concentration increased to 0.023M. In the presence of nickel and cobalt about 0.062M thiosulphate was generated at the 4th hour. At the 24th hour, the thiosulphate concentration reached 0.076 and 0.093M respectively in the presence of nickel and cobalt. During zinc precipitation, the thiosulphate concentration was increased to 0.101M in the presence of cobalt. There was no significant generation of thiosulphate by adding zinc powder to the solution with 0.03M of nickel.

4.2.5 Effect of Sulphur compounds

The effects of sulphite, sulphate, tetrathionate and their combination on the stability of thiosulphate and sulphite were investigated in this series of tests. The test conditions are summarized in Table 4-3

Table 4-3 Sulphur Compound Additives Reagent Conditions

No.	Sodium Sulphite (M)	Sodium Sulphate (M)	Sodium Tetrathionate (M)
S-S-1	0	0	0.075
S-S-2	0.3	0	0
S-S-3	0	0.3	0
S-S-4	0.3	0	0.075
S-S-5	0.3	0.3	0.075
S-S-6	0	0.3	0.075
S-S-7	0.3	0.3	0
S-S-8	0	0	0

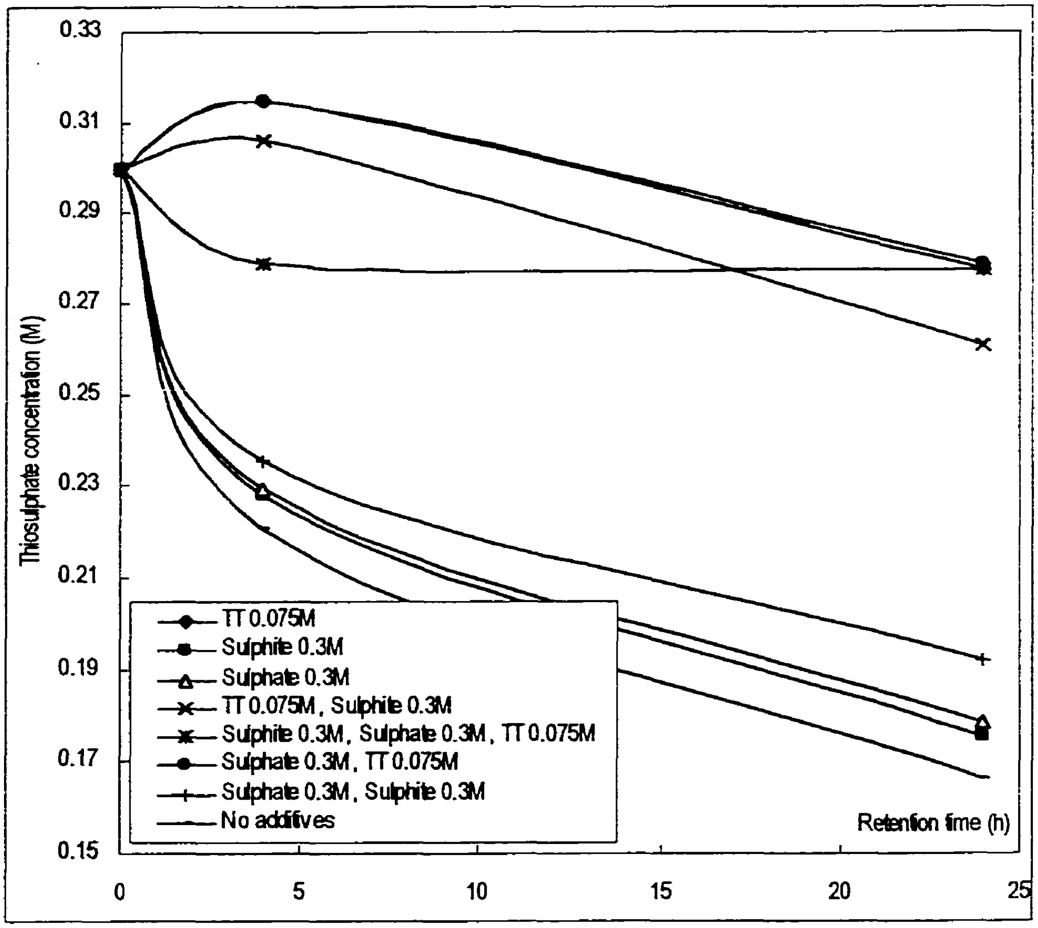

Figure 4-21 Effect of Sulphur Compounds (as Additives) on Thiosulphate Decomposition Curves

(Thiosulphate 0.3M, Ammonia 3M, Copper sulphate 0.03M)

Figure 4-21 shows that solutions with 0.075M of tetrathionate additive gave a better thiosulphate stability. The decomposition curves of these solutions stay on the top of this chart. The decomposition curves of those solutions without tetrathionate additive stay on the bottom part.

Thiosulphate concentrations in the solutions with tetrathionate additions ranged from 0.261 to 0.279M at the 24th hour and 0.286 to 0.301M after zinc precipitation.

Thiosulphate decomposition was 7% to 13% at the 24th hour and restored to 95% to 100% of the initial thiosulphate concentration by zinc precipitation.

Thiosulphate concentrations in the solution containing no tetrathionate were lower than 0.21M at the 24th hour. Thiosulphate decomposition ranged from 36% to 45%. After zinc precipitation, the thiosulphate concentration ranged from 0.19M to 0.21M. About 63% to 68% of thiosulphate was remained.

Beside the measurement of the thiosulphate concentrations, sulphite was also measured in this group of tests. The solutions with sulphite addition will be shown in a Figure 4-22. Those solutions without sulphite addition will be shown in another figure (Figure 4-23).

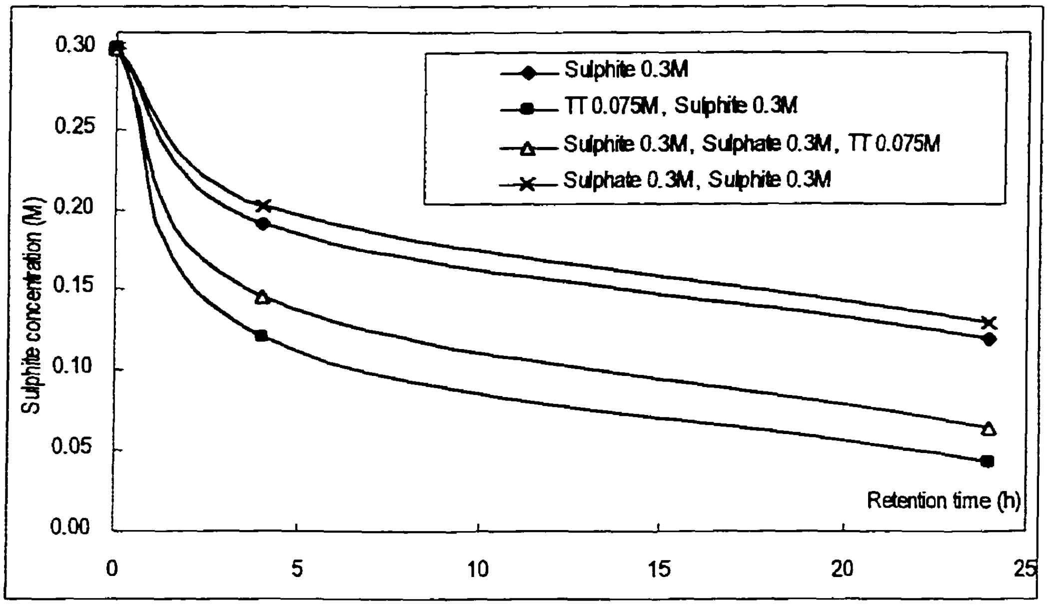

Figure 4-22 Effect of Sulphur Compounds on Sulphite Decomposition Curves
(Thiosulphate 0.3M, Ammonia 3M, Copper sulphate 0.03M)

Figure 4-22 shows the effect of sulphate, tetrathionate and their combination on the stability of sulphite in a solution containing 0.3M of thiosulphate and sulphite. Results demonstrated that the solution containing tetrathionate gives a poor stability of sulphite. The solution containing sulphite and sulphate combination reduced the sulphite concentration to 0.13M and 0.119M respectively at the 24th hour. The decomposition of sulphite was 56.7% and 60.3% respectively.

Sulphite concentration was reduced to 0.064M and 0.043M at the 24th hour in the solution containing the combination of tetrathionate, sulphate and sulphite and the combination of tetrathionate and sulphite. The decomposition of sulphite was 78.7% and 85.7% respectively. After zinc precipitation, the sulphite concentration was restored to 0.087M and 0.075M respectively, which was 29% and 25% of the initial sulphite concentration.

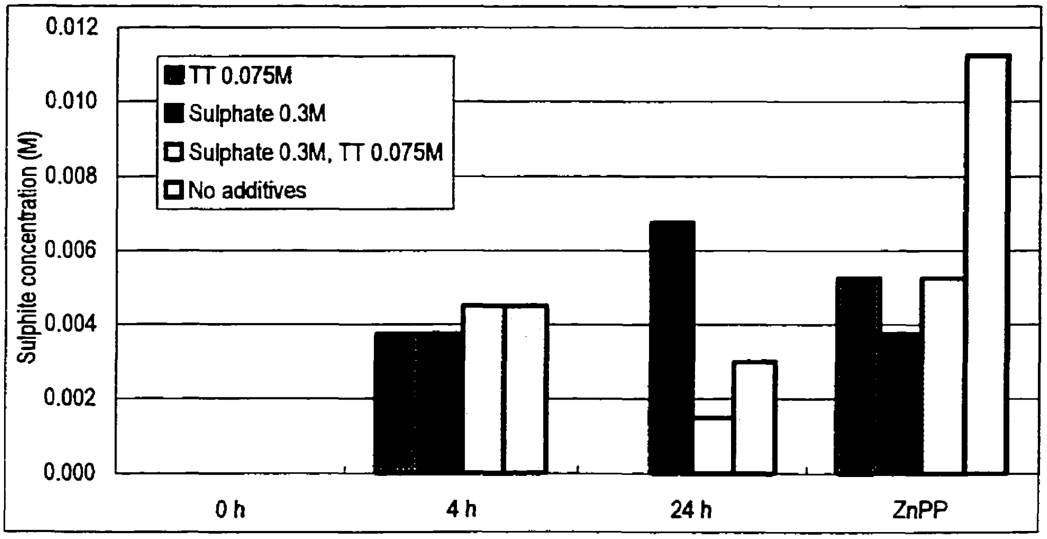

Figure 4-23 Effect of Sulphur Compounds on Sulphite Generation

(Thiosulphate 0.3M, Ammonia 3M, Copper sulphate 0.03M)

Figure 4-23 shows the effect of sulphate, tetrathionate and their combination on the generation of sulphite in a 0.3M of thiosulphate solution without sulphite addition. Without any additives, in the thiosulphate solution, 0.0045M of sulphite was produced at the 4th hour and 0.003M of sulphite was produced at the 24th hour. After zinc precipitation, more sulphite was produced up to a concentration of 0.0112M. With the addition of sulphite and tetrathionate, the generation of sulphite was about the same, i.e., 0.0037M and 0.0045M sulphite. At the 24th hour, the sulphite concentration was reduced to nil in the solution containing tetrathionate and to 0.0015M in the solution containing the combination of tetrathionate and sulphate. In a solution containing sulphate, the sulphite concentration did increased to 0.0067M at the 24th hour. After zinc precipitation, the sulphite concentration increased to 0.0052M. However, the sulphite concentration was decreased 0.0037M in the solution containing sulphate.

4.2.6 A Comparison Between EDTA and Zinc in Thiosulphate Regeneration

To study the extent of thiosulphate regeneration in the zinc precipitation stage, a comparison test was conducted to study the effect of chelating agent and zinc powder. The test conditions are listed in Table 4-4.

Table 4-4 Operating Conditions for EDTA/Zn Comparison Tests

Experiment	Operation	EDTA (M)	Zn (g/L)
ZnEDTA-1	Zinc precipitation in 50 ml solution for 5 min	0	12
ZnEDTA-2	EDTA was added into 50 ml solution (5 min)	0.06	0
ZnEDTA-3	Zinc precipitation (5 min) after EDTA was added into 50ml solution	0.06	12
Remark:	The thiosulphate initial concentration in the oxidized solution was 0.25M. EDTA and copper concentration is 0.03M. Ammonia concentration is 3M.		

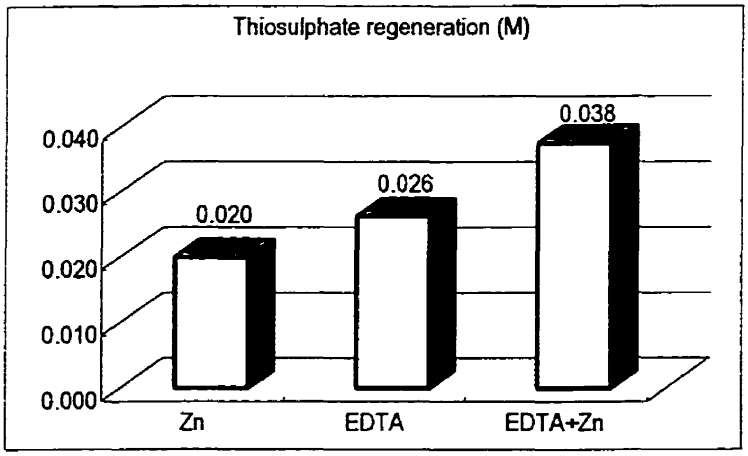

Figure 4-24 Effect of Zn and EDTA on Thiosulphate Regeneration

(Conditions are listed in table 4-4)

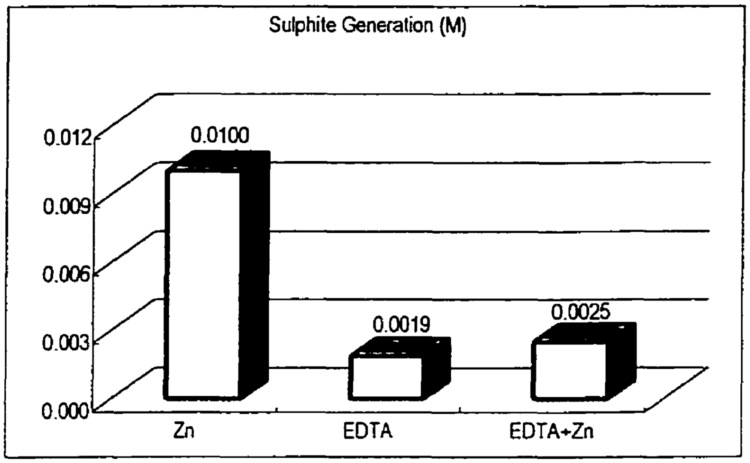

Figure 4-25 Effect of Zn and EDTA on Sulphite Generation

(Conditions are listed in table 4-4)

Figure 4-24 shows the effect of zinc powder and EDTA on the generation of thiosulphate. Adding 12 g/L zinc powder into a solution containing 0.25M of thiosulphate. 0.02M of thiosulphate was generated. Adding 0.06M of EDTA into the same solution, 0.026M of thiosulphate was generated. Adding the combination of zinc and EDTA, 0.038M of thiosulphate was generated.

Figure 4-25 shows the production of sulphite by adding EDTA, Zn and their combination. Results indicate that zinc powder can create more sulphite and less thiosulphate as compared with EDTA. The addition of zinc powder generated 0.01M of sulphite. The presence of EDTA reduced the amount of sulphite to 0.0025M or lower.

5. Results from Gold Leaching Tests

Results from thiosulphate decomposition tests explored the major effect of a copper species and oxygen supply on the thiosulphate stability. EDTA and other strong chelating agents are promising additives, which can chelate copper ion and reduce thiosulphate decomposition. A lower thiosulphate concentration is preferred for its stability. Proper solution pH should be determined for every reagent combination. A higher ammonia concentration is helpful to thiosulphate stability. Thiosulphate decomposition was proved to be a series of oxidation reactions. The primary product of thiosulphate decomposition was tetrathionate. The secondary product was sulphite. The final product was sulphate. Trithionate possibly exists as a product of tetrathionate-sulphite reaction.

It was known that both thiosulphate decomposition and gold extraction are oxygen-consuming reactions catalysed by copper species. There are conflicts between preventing thiosulphate oxidation and promoting gold extraction. Gold leaching tests in this investigation were carried out in order to enhance the thiosulphate stability and gold extraction.

Copper species were studied in the most important parts of this investigation. Oxygen supply was also briefly studied. Low reagent strength in gold leaching was investigated partly. Many other variables were studied as well in this stage of experiments. Unless otherwise specified, the gold leaching tests were carried out under conditions as listed in Table 5-1.

Table 5-1 Operating Conditions for Gold Leaching Test

Experiment type	: gold leaching	Leaching time	: 24 hours
Objective Ore Samples	: Hope Brookeee	Temperature	: 20~25 °C
Vessel	: 2520 ml, capped glass bottle	Reagent Refilling	: No
Stirring Method	: rotating at 59.5 rmp	Ore Sample	: 200 g
Grinding Method	: laboratory rod mill at 60%	Grinding time	: 20 min
Particles Size	: 85% -200 mesh	Solution Volume	: 250 ml
Oxygen Supply	: air in Capped Bottles	Solution pH	: 10.2
Air Refilling	: at the 4th hour	Pulp Density	: 44.4%
Remarks: All experiments in a test group were conducted simultaneously			

5.1 Comparisons on The Effects of Various Additives

In open-vessel thiosulphate decomposition tests, several types of additives were compared for improving thiosulphate stability. EDTA gave an outstanding performance. Sulphite and sulphate were positive but limited. To explore their effects on gold extraction, two groups of gold leaching tests were conducted on two types of ore samples.

5.1.1 Comparison Tests on Hope Brookeee Ore

The composition standard lixiviant used in this series of tests include 0.3M of thiosulphate, 0.03M of copper sulphate, and 3M of ammonia. The effects of various additives on gold extraction and thiosulphate consumption were studied. The concentration of additives is listed in Table 5-2.

Table 5-2 Additives Condition for Test Group "E-ADD"

Experiment No.	Additives	Additives concentration (M)
E-Add-1	Nothing	0
E-Add-2	Sulphate	0.1
E-Add-3	Sulphite	0.1
E-Add-4	Sulphur Dioxide	0.1
E-Add-5	Sulphide	0.1
E-Add-6	Bisulphite	0.1
E-Add-7	EDTA	0.03
E-Add-8	NTA	0.03
E-Add-9	Glycine	0.06

NTA, Ammoniatriacetic Acid, is perhaps the most important strong copper complexing agent other than EDTA.

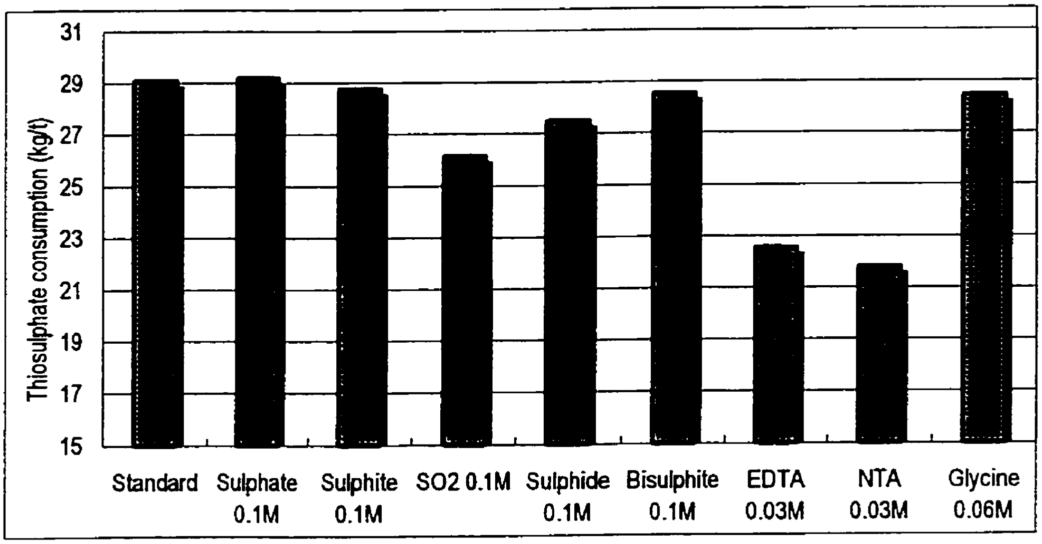

Figure 5-1 Effect of Various Additives on Thiosulphate Consumption

(Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M)

Figure 5-1 shows the thiosulphate consumption in kilograms per ton of ore. Under the standard condition (without additives) 29 kg/t of thiosulphate was consumed. The sulphate and sulphite did not improve the thiosulphate stability. Sulphide and bisulphite showed limited improvement for about 1 or 2 kg/t. Sulphur dioxide saved about 3 kg/t. Glycine, a kind of simple amino acid, saved less than 1 kg/t. EDTA and NTA saved about 7 kg/t. Chelating agents showed obvious advantages over the other additives.

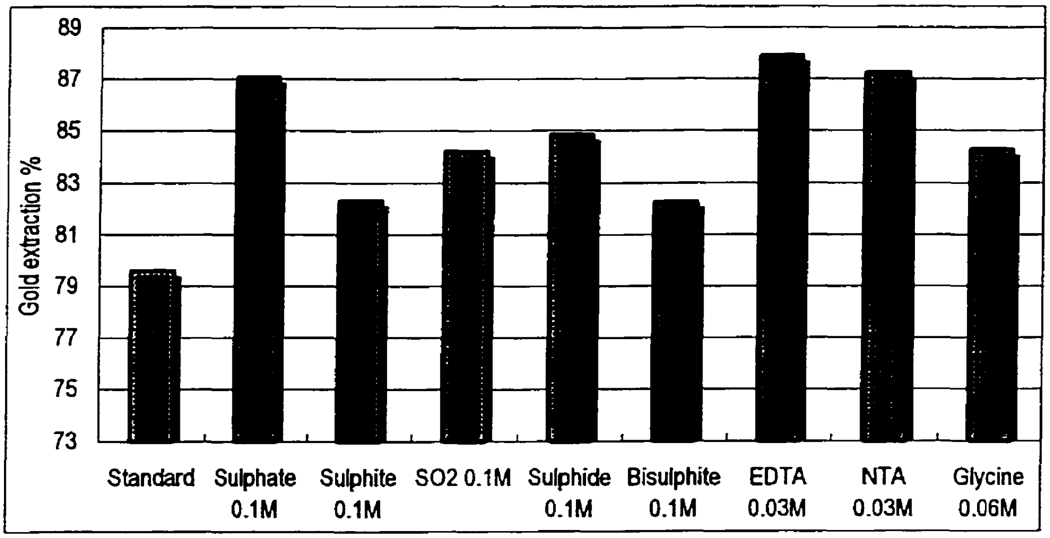

Figure 5-2 Effect of Various Additives on Gold Extraction
(Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M)

Figure 5-2 shows that, under the standard condition, a gold extraction was about 80%. All additives improved the gold extraction to some extent. Sulphate anion improves gold extraction for about 8%. EDTA and NTA increase gold extractions to more than 87.23%. The results demonstrated the advantages of EDTA and NTA additives. They improved not only the thiosulphate stability but also the gold extraction.

5.1.2 Comparison Tests on M Ore

M ore was applied in a series of gold leaching tests using the same standard lixiviant composition as with Hope Brookeee ore. EDTA, sulphite and sulphate additives were studied in this series of tests

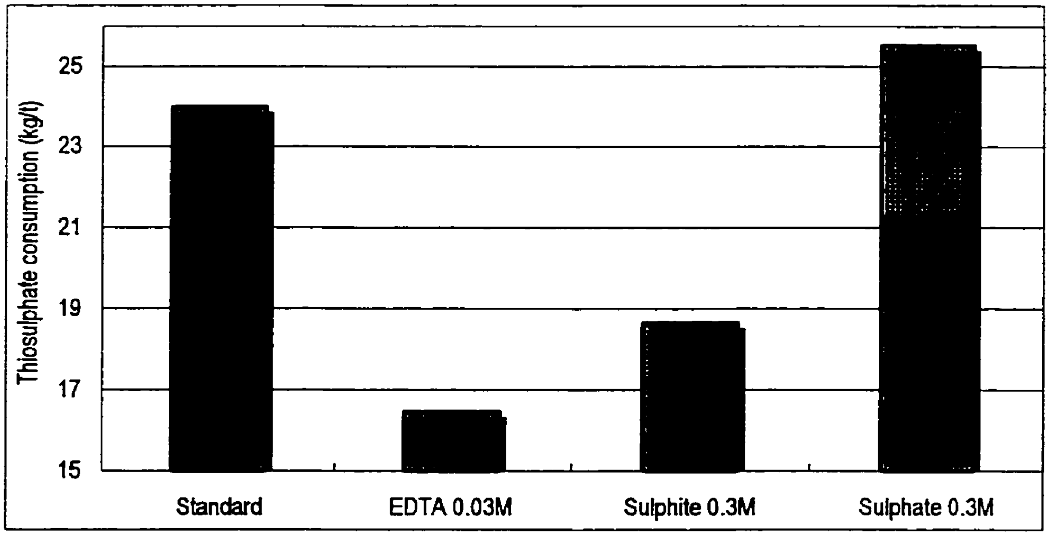

Figure 5-3 Effect of Various Additives on Thiosulphate Consumption for M Ore
(Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M)

Figure 5-3 shows the effect of sulphite, sulphate and EDTA on thiosulphate stability and consumption. 57.34% of thiosulphate was remained in the standard solution after 24 hours with a consumption of 23.95 kg/ton. The addition of EDTA increased the final thiosulphate concentration by 13%. The sulphite additive increased the final thiosulphate by 9%. The thiosulphate consumptions by adding EDTA and sulphite were respectively reduced to 16.45 and 18.64 kg/ton. The sulphate salt did not improve the stability of thiosulphate under this condition.

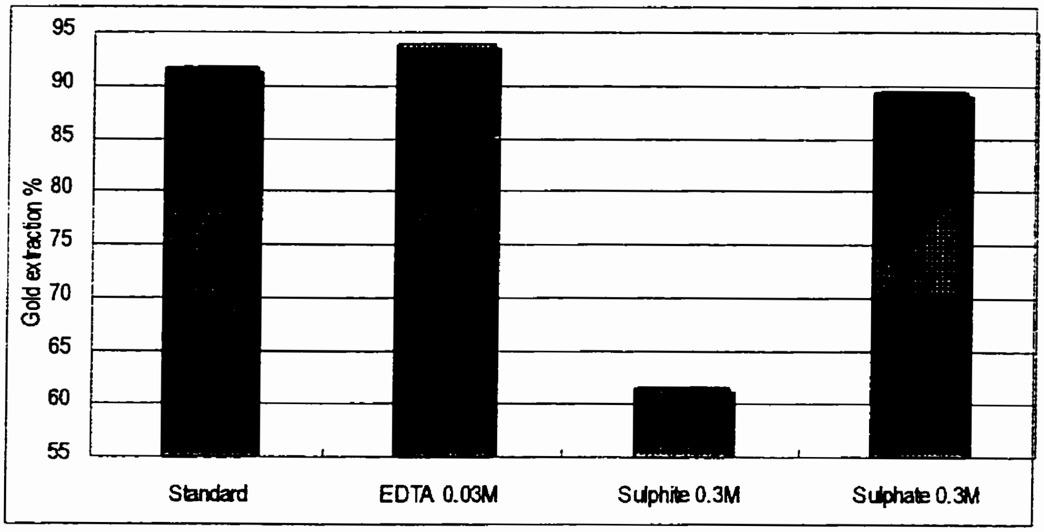

Figure 5-4 Effect of Various Additives on Gold Extraction for M Ore
(Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M)

Figure 5-4 shows the effect of additives on gold extraction. Results show that 91.7% of gold was extracted in the standard solution without additives. The sulphite reduced the gold extraction to 61.55%. The addition of EDTA improves not only the stability of thiosulphate but also enhanced gold extraction to 93.92%. Sulphate did not significantly affect the gold extraction and thiosulphate stability under this condition.

5.2 Effects of Copper Ion and its Complexes

Based on the initial study on EDTA as a strong chelating agent for copper ion, it can be concluded that copper species have very important influences on the gold extraction as well as thiosulphate stability performance.

The source of major dissolved copper is copper sulphate or copper tetra amine. Copper minerals can be one of the copper suppliers. Copper dissolved in ammonia solution may form copper amine complexes. Copper can also be precipitated by sulphide anion or dissolved to or from copper minerals. The stability of these species is decided by many factors: ammonia concentration, solution pH, copper sulphate addition amount and thiosulphate concentration. Many additives such as chelating agents and sulphur compounds can significantly change the state of copper species in solution.

Reagent compositions in this investigation were based on the optimum conditions developed by previous researches on Hope Brookeee ore. (Yen et al., 1999) (Yen et al., 1996)

5.2.1 Effect of EDTA as a Copper Chelating Agent

EDTA did improve thiosulphate stability and gold extraction as mentioned in previous sections. In this series of tests, the effects of EDTA concentration and its ratio to copper and ammonia on the gold extraction and thiosulphate consumption were studied.

5.2.1.1 Effect of EDTA Concentration

In the first series of tests, EDTA concentration was studied in a range from 0.015M to 0.06M.

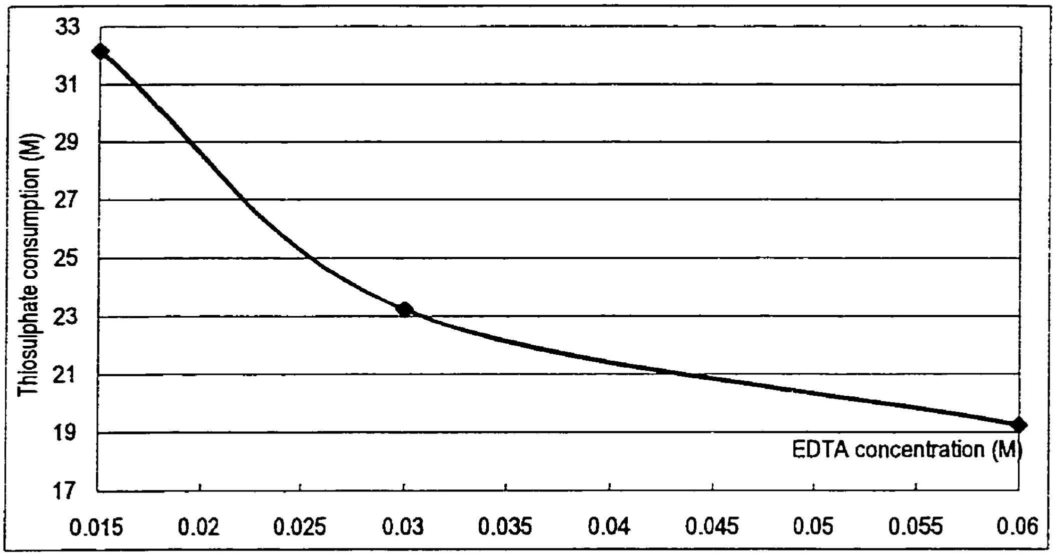

Figure 5-5 Effect of EDTA Concentration on Thiosulphate Consumption (A)
(Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M)

Figure 5-5 shows the effect of EDTA concentration on the thiosulphate stability. When the EDTA concentration was increased from 0.015M to 0.03 and 0.06M, the remaining thiosulphate was increased from 46.94% to 59.92% and 67.19% respectively. The consumption of thiosulphate was reduced from 32.14 kg/t to 23.2 and 19.23 kg/ton respectively.

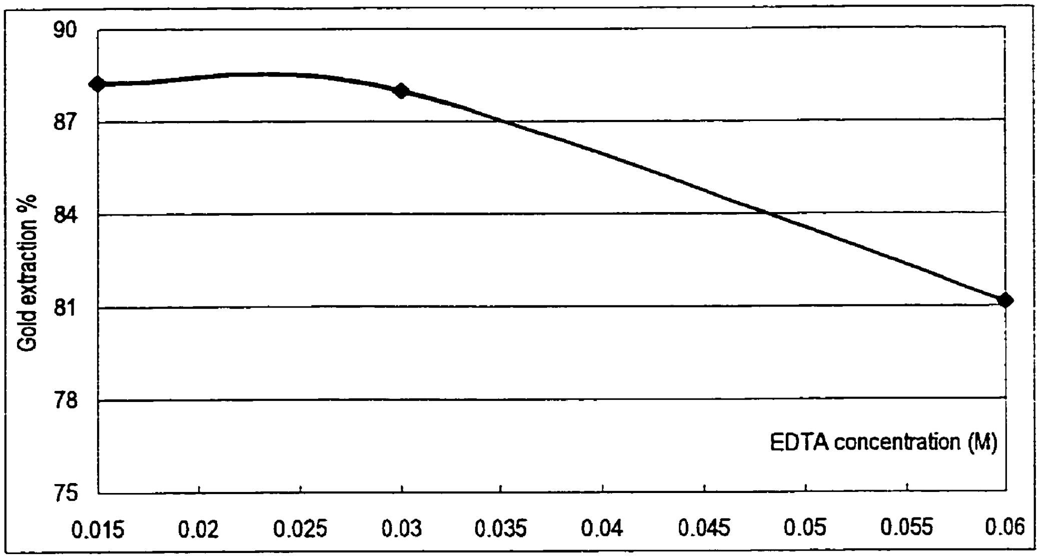

Figure 5-6 Effect of EDTA Concentration on Gold Extraction (A)
(Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M)

Figure 5-6 shows the effect of EDTA concentration on the extraction of gold. The concentration of EDTA at 0.01M and 0.03M gave gold extractions of 88.23% and 87.96% respectively. When the EDTA concentration was 0.06M, gold extraction decreased sharply to 81.14%.

More tests were carried out to study the effect of EDTA concentration ranging from 0.03M to 0.04M on thiosulphate stability.

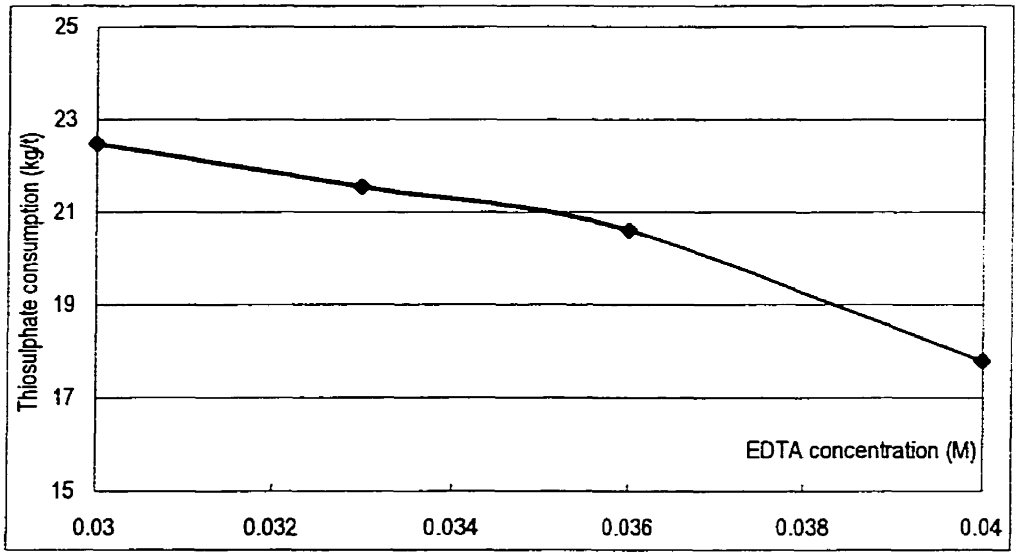

Figure 5-7 Effect of EDTA Concentration on Thiosulphate Consumption (B)
(Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M)

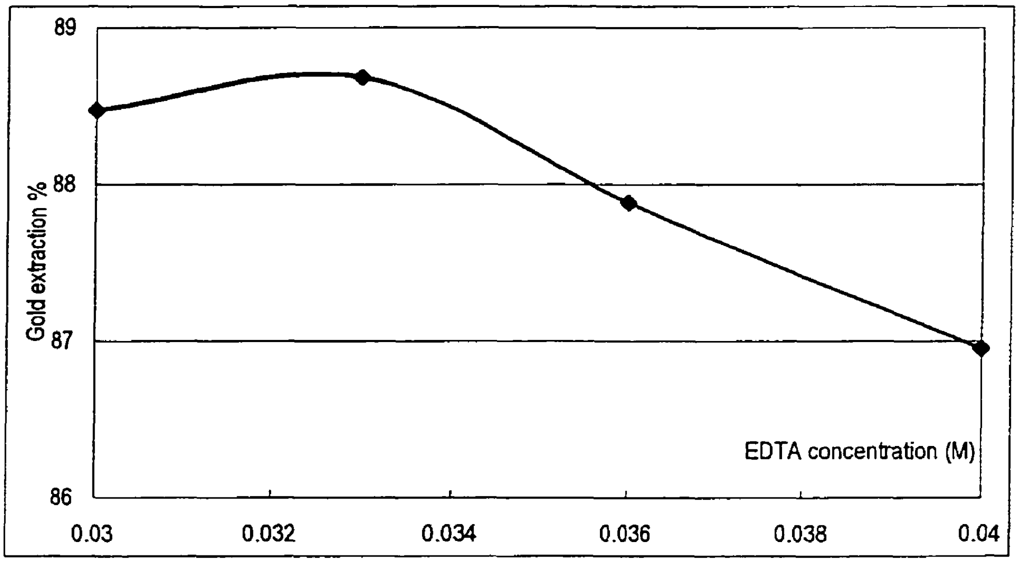

Figure 5-8 Effect of EDTA Concentration on Gold Extraction (B)
(Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M)

Figure 5-7 shows that increase of EDTA concentration from 0.03M to 0.04M increased the thiosulphate final concentration from 0.18 to 0.21M. The consumption was reduced from 22.46 to 17.78 kg/t respectively.

Figure 5-8 shows that gold extraction was reduced from 88.47% to 86.95% with an increase of EDTA concentration from 0.03M to 0.04M. The best gold extraction, 88.68%, was reached when the EDTA concentration was 0.033M.

5.2.1.2 Effect of Ammonia Concentration in Gold Leaching with EDTA-cu Solution

The evidence of the above results indicated that the monitoring of copper species in the lixiviant have a great effect on thiosulphate stability and gold extraction. There are three major complexing agents for copper ion, ammonia, thiosulphate and EDTA. In the following series of tests, copper, ammonia and EDTA were used in various combination ratios.

In the first test group, the concentration of EDTA and copper sulphate was fixed at 0.03M. The ammonia concentration was varied from of 1 to 6 M.

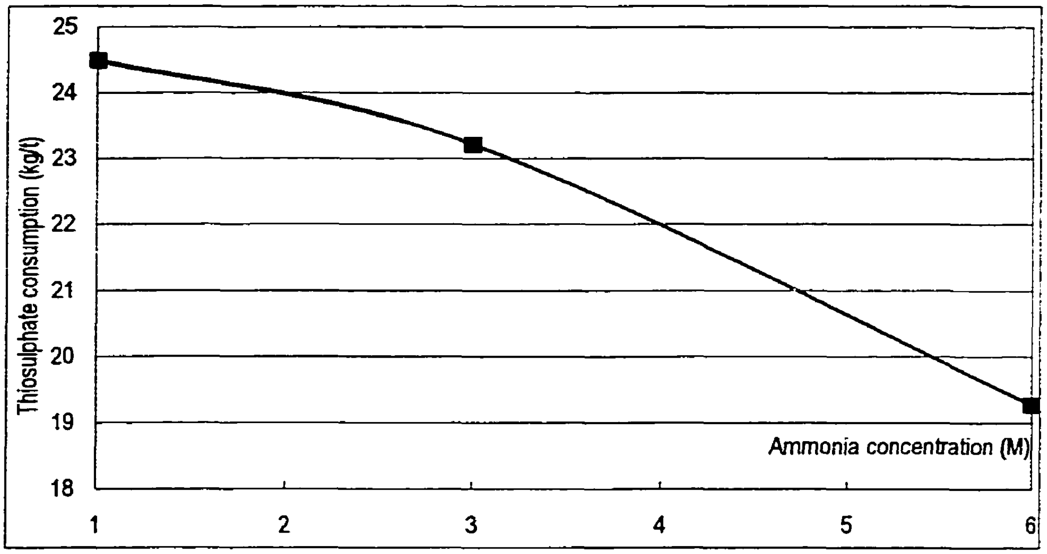

Figure 5-9 Effect of Ammonia on Thiosulphate Consumption When EDTA and Copper Sulphate Concentrations Were Constant

(Thiosulphate 0.3M, EDTA and Copper sulphate 0.03M)

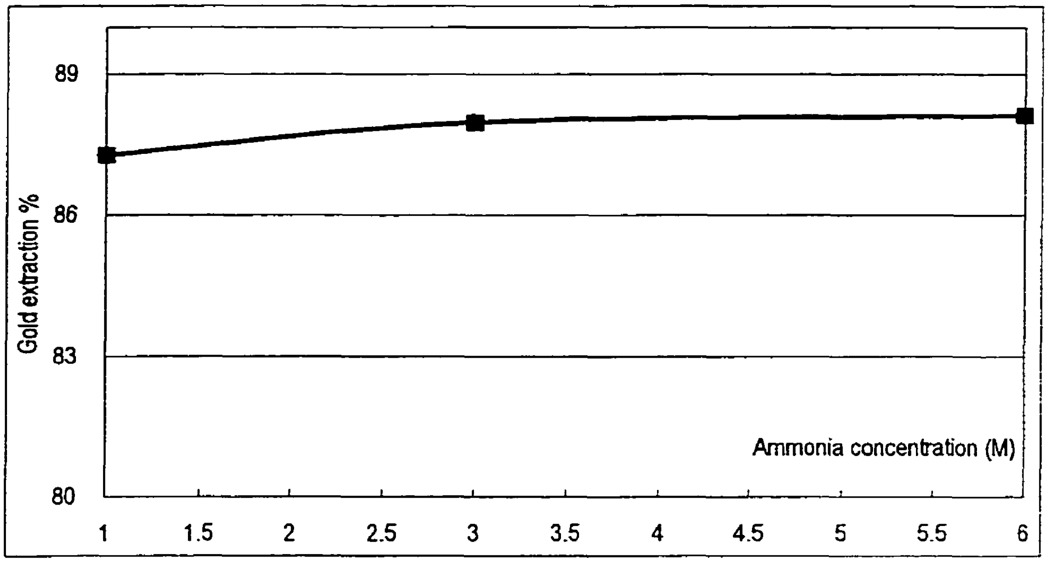

Figure 5-10 Effect of Ammonia on Gold Extraction When EDTA and Copper Sulphate Concentrations Were Constant

(Thiosulphate 0.3M, EDTA and Copper sulphate 0.03M)

Figure 5-9 shows that an increase of ammonia concentration reduced thiosulphate consumption. When the ammonia concentration was 1M, 57.69% of thiosulphate remained at the 24th hour with 24.48 kg/t of thiosulphate consumption. When the ammonia concentration was 3M, 59.92% of thiosulphate remained with 23.2 kg/t of thiosulphate consumption. The consumption was further reduced to 19.26 kg/t when the ammonia concentration was 6M. Figure 5-10 shows that the higher the ammonia concentration, the better the gold extraction. When the ammonia concentration was increased from 1M to 6M, the gold extraction was increased slightly from 87.26% to 88.11%.

5.2.2 Effect of Copper Amine as Catalyst

Copper tetra amine is known as an effective catalyst in gold extraction catalysis. Based on the study of EDTA, it was also indicated that a very small amount of copper catalyst was required for gold extraction. Too much copper would cause high reagent consumption.

In the following series of tests, copper tetra amine was used to replace copper sulphate.

5.2.2.1 Initial Investigation on Copper Amine Gold Leaching

A serial of tests were carried out to define the proper range of copper tetra amine and ammonia concentrations required for producing acceptable thiosulphate consumption and gold extraction. The test conditions are listed in Table 5-3.

Table 5-3 Reagent Conditions for Test Group "E-CA3"

Experiment No.	Ammonia (M)	Copper tetra amine (M)
CA3-1	0.10	0.0016
CA3-2	0.10	0.0059
CA3-3	0.30	0.0016
CA3-4	0.30	0.0051
CA3-5	0.60	0.0016
CA3-6	0.60	0.0096

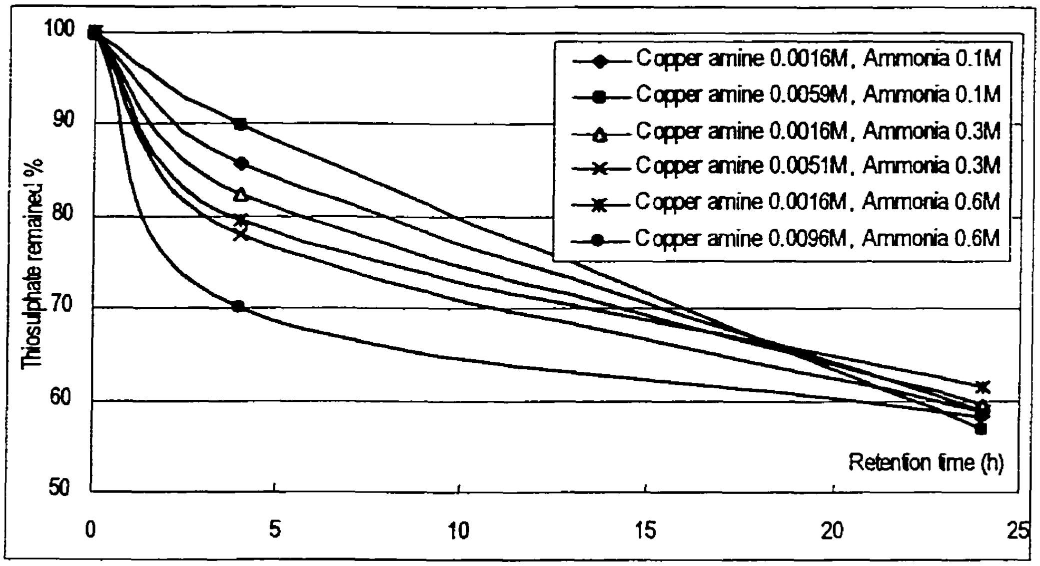

Figure 5-11 Effect of Copper Tetra Amine and Ammonia Concentration on Thiosulphate Decomposition Curves

(Thiosulphate 0.3M, pH 9.6-9.8)

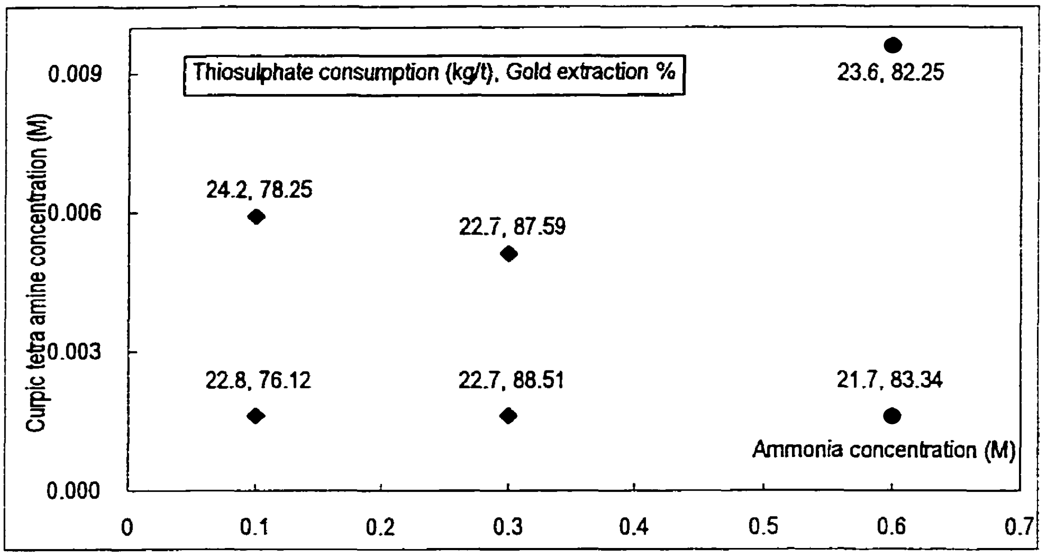

Figure 5-12 Effect of Ammonia and Copper Tetra Amine Concentrations on Thiosulphate Consumption and Gold Extraction

(Thiosulphate 0.3M, pH 9.6-9.8)

Figure 5-11 shows the effect of ammonia and copper tetra amine combination on the thiosulphate stability. At the 4th hour, the solution containing a higher concentration of copper tetra amine caused a lower stability of thiosulphate. Only 70% of thiosulphate remained at the 4th hour using 0.0096M of copper tetra amine, and 85% remained using 0.0016M copper tetra amine. However, there were slight differences in thiosulphate stability for various ammonia and copper tetra amine combinations at the 24th hour. The remaining thiosulphate ranged from 58.88% to 61.56%.

Figure 5-12 shows the effect of ammonia and copper tetra amine combinations on thiosulphate consumption and gold extraction. Results indicated that, when copper tetra amine concentration ranged from 0.0096 to 0.0016M, thiosulphate consumption was reduced to about 23 kg/t. The concentration of ammonia has more significant influence on gold extraction. The best gold extraction (88occurred when ammonia concentration was 0.3M, 88.59% of gold was extracted. The increase of ammonia concentration from 0.3 to 0.6M reduced the gold extraction to 83%. The decrease of ammonia concentration reduced the gold extraction to 78 or 76%.

5.2.2.2 Effect of Ammonia Concentration in Copper Amine Gold Leaching

In this series of tests, ammonia concentration was studied in the range of 0.05M and 0.6M in a fixed concentration of copper amine at 0.0016g/L.

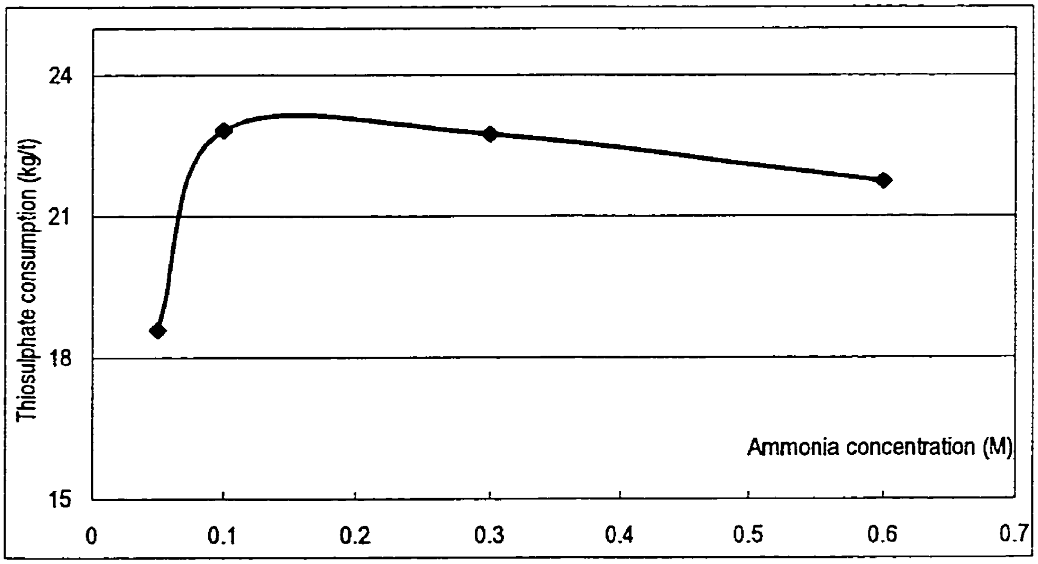

Figure 5-13 Effect of Ammonia Concentration on Thiosulphate Consumption in Copper Tetra Amine Gold Leaching

(Thiosulphate 0.3M, Copper tetra amine 0.4 g/L)

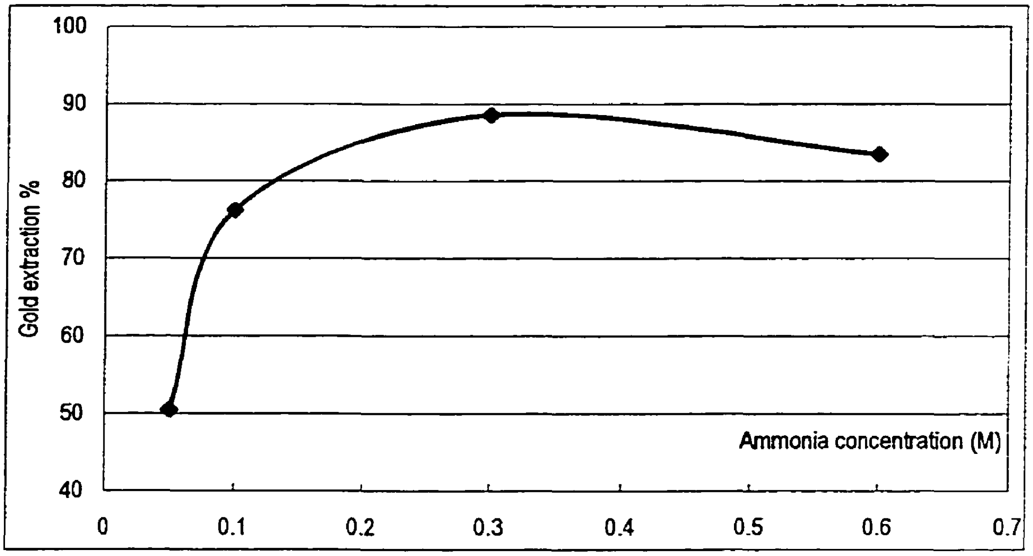

Figure 5-14 Effect of Ammonia Concentration on Gold Extraction in Copper Tetra Amine Gold Leaching

(Thiosulphate 0.3M, Copper tetra amine 0.4 g/L)

Figure 5-13 shows that the maximum thiosulphate consumption occurred when the ammonia concentration was 0.1M. The decrease of ammonia concentration from 0.1M to 0.05M reduced the thiosulphate consumption from 22.8 kg/t to 18.58 kg/t. The increase of ammonia concentration from 0.1M to 0.6M gradually reduced the thiosulphate consumption to 21.72 kg/t.

As shown in Figure 5-14, the gold extraction increased sharply from 50% to 88.51% when the ammonia concentration was increased from 0.05M to 0.3M. A further increase of ammonia concentration to 0.6M caused the gold extraction to be slightly lower at 83.34%.

5.2.2.3 Effect of Ammonia Concentration and Copper Tetra Amine Combination

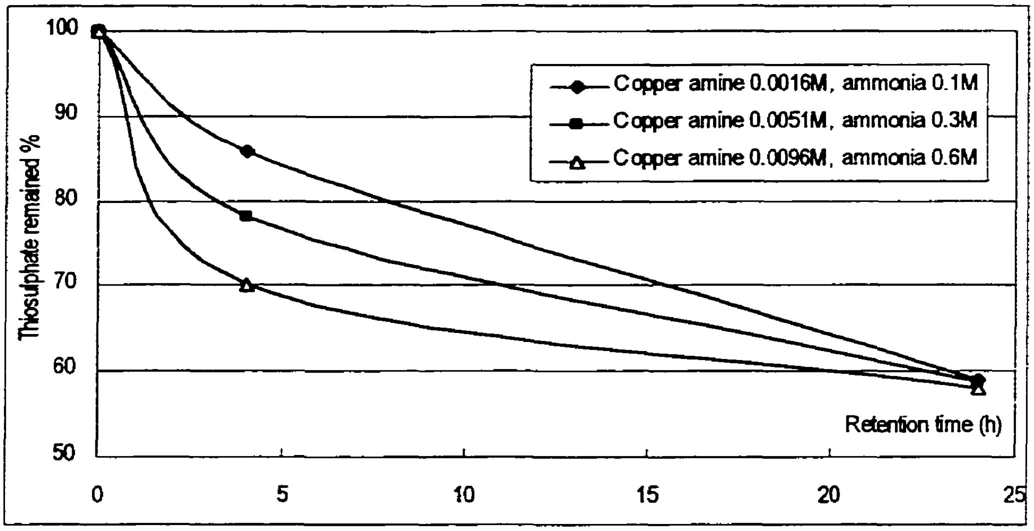

Figure 5-15 Effect f Ammonia and Copper Tetra Amine Concentration on Thiosulphate Decomposition Curves

(Thiosulphate 0.3M)

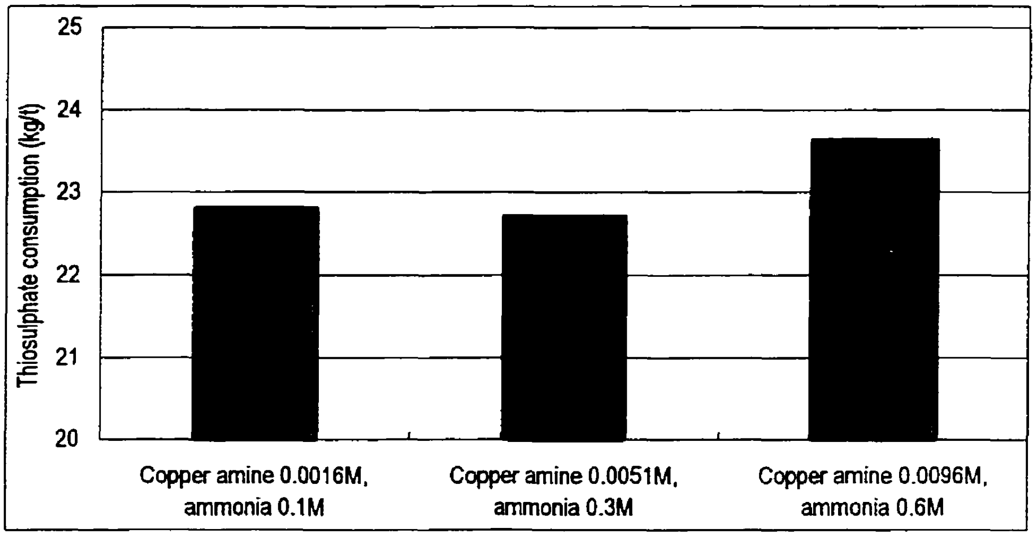

Figure 5-16 Effect of Ammonia and Copper Tetra Amine Concentration on Thiosulphate Consumption

(Thiosulphate 0.3M)

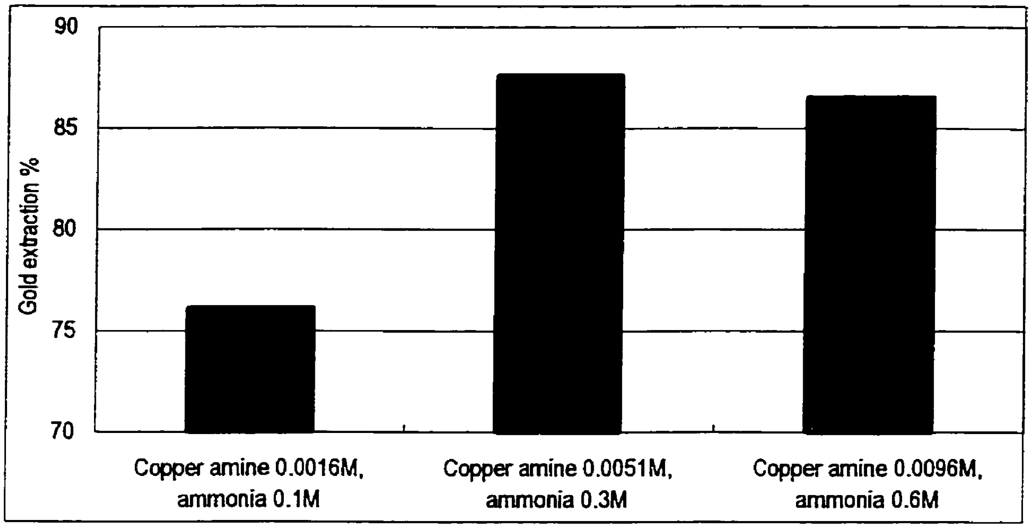

Figure 5-17 Effect of Ammonia and Copper Tetra Amine Concentration on Gold Extraction

(Thiosulphate 0.3M)

Figures 5-15 and 5-16 show that the final thiosulphate consumption has little relation with copper tetra amine and ammonia concentrations when the ratio of these two reagents was kept constant. At the 4th hour, there was a big difference (15.54%) between the thiosulphate remaining percentages. High concentrations of copper and ammonia led to higher thiosulphate decomposition. At the 24th hour, the thiosulphate concentration was about 58% of the original concentration. Figure 5-17 shows that the combination of 0.3M ammonia and 0.0051M copper tetra amine gave the best gold extraction at 87.59%. The combination of 0.1M ammonia and 0.0016M copper tetra amine gave a lower gold extraction at 76.12%.

5.2.3 Gold Leaching with Lower Copper Content

For reducing thiosulphate consumption, the addition of copper concentrations was reduced to a minimum without affecting the gold extraction. In one series of tests, there was not copper sulphate added in the lixiviant. In another series of tests, nickel sulphate was used to replace copper sulphate.

Two types of ore samples were used in the following tests to explore the effect of low copper sulphate addition in gold leaching.

5.2.3.1 Gold Leaching of Hope Brookeee Ore at Low Copper Concentration

Copper concentrations in the range of 0.00075M to 0.03M and 0 to 0.03M of EDTA additive were used to leach a Hope Brookeee ore in a solution containing 0.3M thiosulphate and 3M of ammonia. The combination of EDTA and copper sulphate concentration is listed in Table 5-4.

Table 5-4 Reagent Conditions for Tests Group "E-CuH"

Experiment No.	EDTA (M)	Copper Sulphate (M)
E-CuH-1	0	0.0015
E-CuH-2	0.0015	0.0015
E-CuH-3	0	0.00075
E-CuH-4	0.00075	0.00075
E-CuH-5	0	0.03
E-CuH-6	0.03	0.03

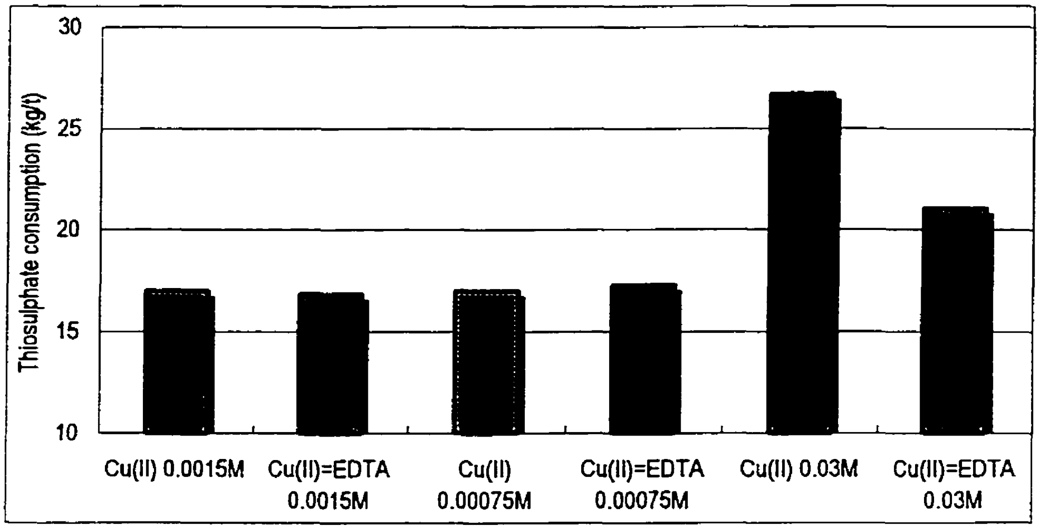

Figure 5-18 Effect of Copper Sulphate and EDTA Concentration on Thiosulphate Consumption

(Thiosulphate 0.3M, Ammonia 3M)

Figure 5-18 shows the effect of copper concentration and EDTA combination on the thiosulphate consumption. The addition of 0.03M EDTA in a 0.03M copper sulphate solution could reduce the thiosulphate consumption from 26.7 kg/t to 21.04kg/t. But when copper sulphate concentration was lower than 0.0015, the thiosulphate consumption was reduced to about 17 kg/t with or without EDTA additive.

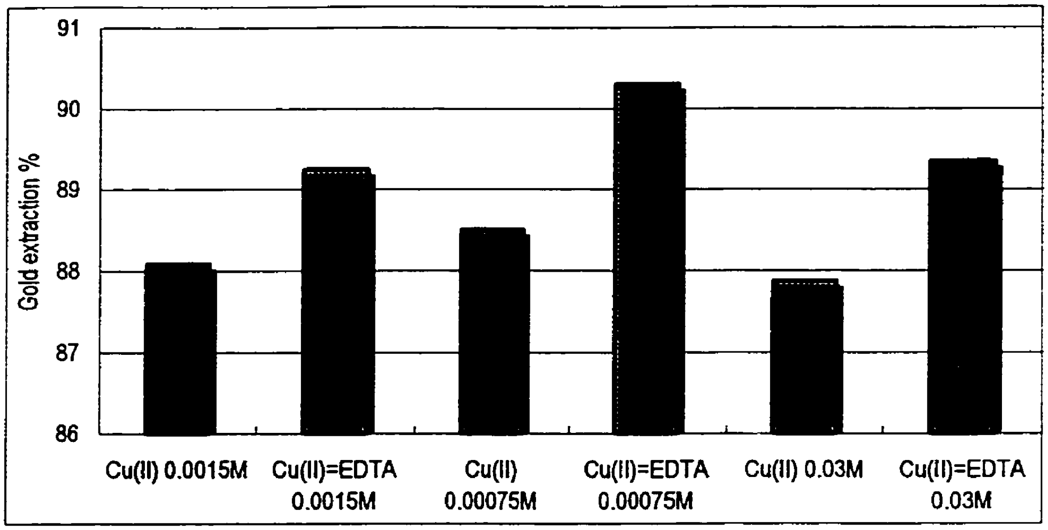

Figure 5-19 Effect of Cu-EDTA Concentration on Gold Extraction
(Thiosulphate 0.3M, Ammonia 3M)

Figure 5-19 shows that the effect of copper and EDTA combination on gold extraction. The solution containing 0.03M copper gave 87.9% gold extraction. The 0.03M of EDTA addition in a 0.03M copper sulphate solution improved the gold extraction to 89.3%. The reduction of copper concentration to 0.0015M or 0.00075M did not reduce the gold extraction. However, the combination of 0.0015M copper sulphate and 0.0015M EDTA gave a gold extraction of 89.2%. The addition of 0.00075M of EDTA in the 0.00075M of copper sulphate solution produced the best gold extraction (90.3%).

5.2.3.2 Gold Leaching of J Ore at Low Copper Concentration

J ore is a type of non-copper bearing high-grade gold ore. The reagent combination for leaching J ore is listed in Table 5-5.

Table 5-5 Reagent Conditions for Test Group "E-Cuj"

Experiment No.	Copper Sulphate (M)	EDTA (M)	Ammonia (M)
E-CuJ-1	0.010	0	3
E-CuJ-2	0.003	0	3
E-CuJ-3	0.001	0	3
E-CuJ-4	0.010	0.01	3
E-CuJ-5	0.001	0	0.3

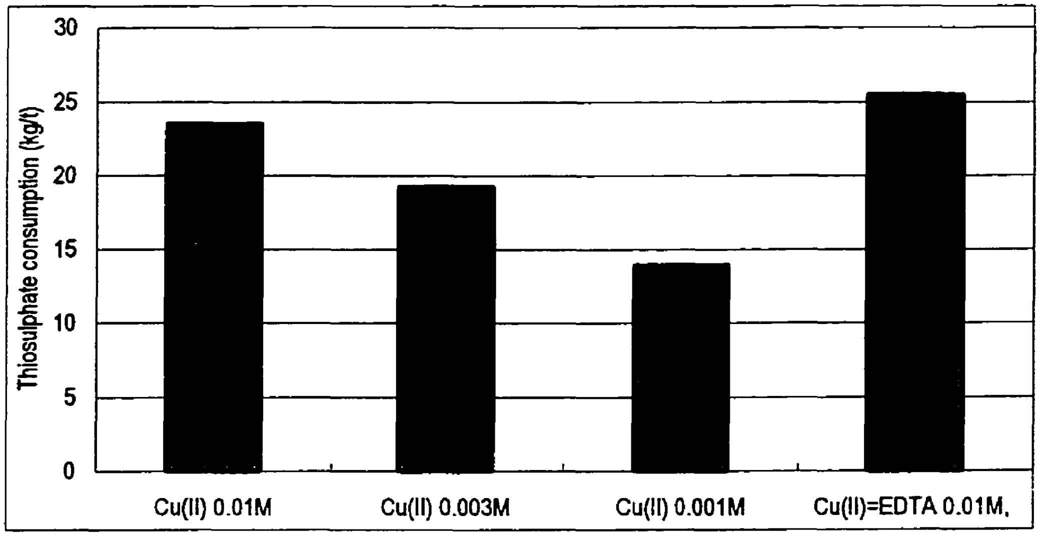

Figure 5-20 Effect of Copper Concentration Thiosulphate Consumption (J Ore)
(Thiosulphate 0.3M, Ammonia 3M)

Figure 5-20 shows that the decrease of copper sulphate concentration from 0.01M to 0.001M reduced the thiosulphate consumption from 23.53 kg/t to 13.9 kg/t. The lowest thiosulphate consumption occurred in the solution containing 0.001M of copper sulphate and 3M of ammonia. The final thiosulphate concentration at the 24th hour was 0.233M with 22.3% decomposition or 13.9kg/t of thiosulphate consumption. When the copper concentration was 0.003M, the thiosulphate consumption increased to 19.2 kg/t. The addition of EDTA in the 0.01M copper sulphate solution did not improve thiosulphate stability.

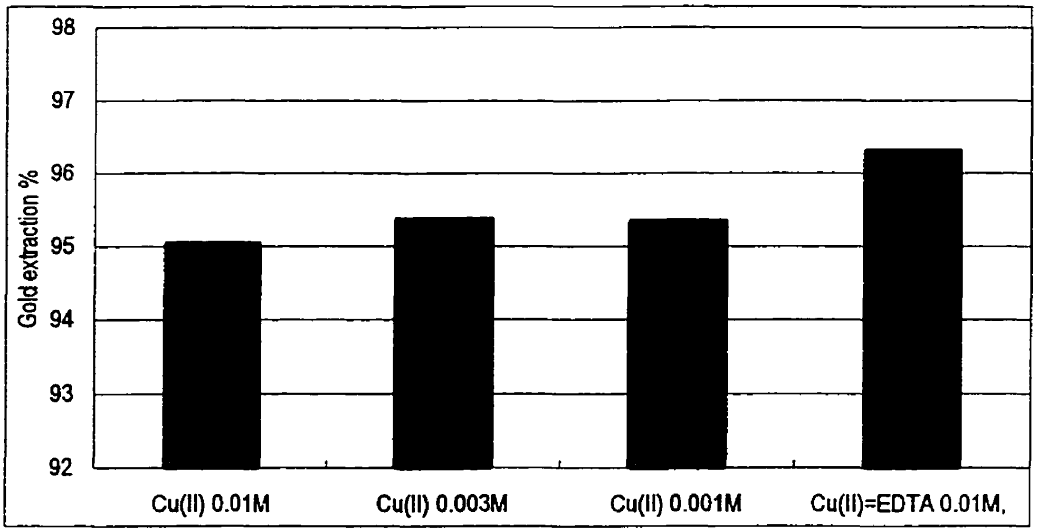

Figure 5-21 Effect of Copper Concentration on Gold Extraction (J Ore)
(Thiosulphate 0.3M, Ammonia 3M)

Figure 5-21 shows that gold extractions in the solutions containing less than 0.01M copper were all above 95%. The best gold extraction, at 96.3%, occurred in a solution containing 0.01M copper and 0.01M EDTA.

5.2.3.3 "Non-copper" Gold Leaching After Pre-conditioning

For ore samples with copper sulphide minerals, a copper catalyst can be supplied by dissolving copper minerals in ammonia. Thus no additional copper reagent was required. To dissolve copper minerals by ammonia, it required conditioning the ore sample with ammonia solution for an extended time.

Both Hope Brookeee and M ore samples were pulped in the bottles containing 250ml of 3M ammonia solution. The pulp was agitated in the capped bottles on rolls. There was no air refilled until the end of pre-condition process. The pre-condition time was set from 24 hours to 72 hours as listed in Table 5-6. After pre-conditioning, thiosulphate was added. In the E-NoCu-3 solution, EDTA was added at a 1:1 ratio with copper concentration (0.00535M).

Table 5-6 Pre-Conditioning Operation and Results

Experiment No.	Ore	Duration time (h)	Extracted Cu concentration (mg/L)
E-NoCu-1	Hope Brookeee	24	190.80
E-NoCu-2	M ore	24	675.00
E-NoCu-3	Hope Brookeee	72	347.80

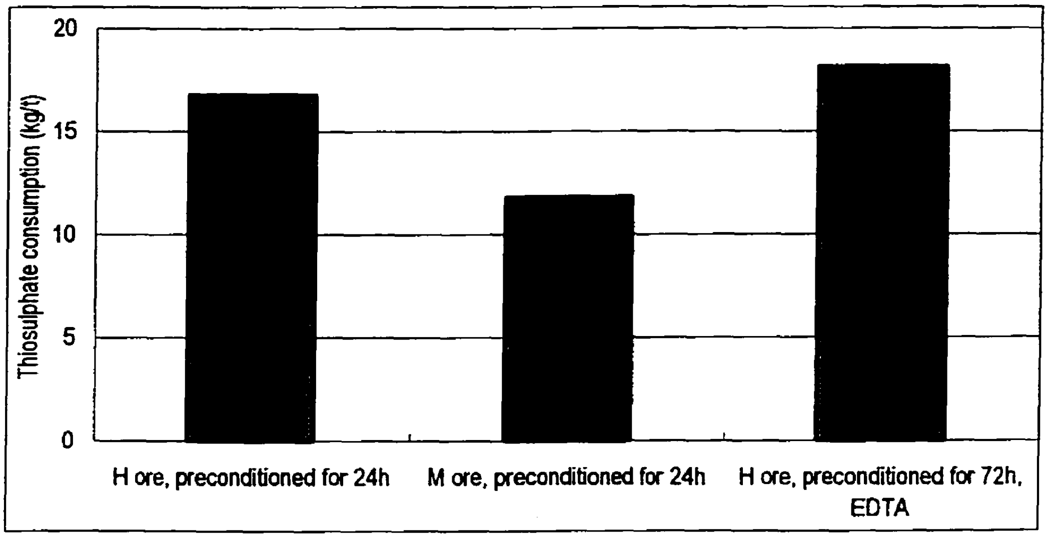

Figure 5-22 Effect Of Pre-conditioning Operation on Thiosulphate Consumption (without Copper Sulphate)

(Thiosulphate 0.3M, Ammonia 3M)

Figure 5-22 shows the effect of pre-conditioning on the thiosulphate consumption. Results show that 16.75 kg/t of thiosulphate was consumed by a Hope Brookeee ore with 24 hours' preconditioning. The same ore with 72 hours pre-conditioning consumed 18.11 kg/t of thiosulphate. For M ore, with 24 hours pre-conditioning, the thiosulphate consumption was only 11.77 kg/t.

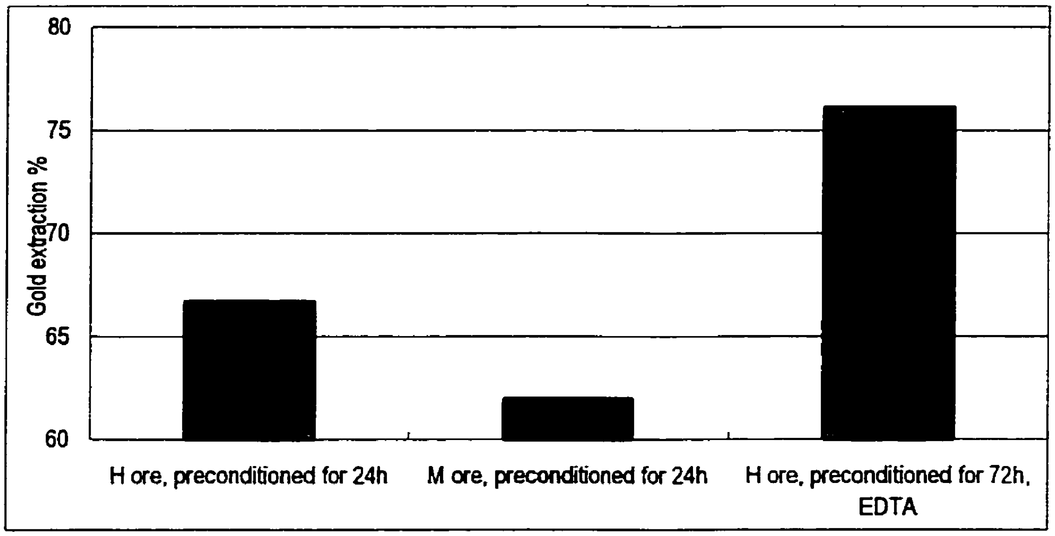

Figure 5-23 Effect of Pre-conditioning Operation on Gold Extraction (without Copper Sulphate)

(Thiosulphate 0.3M, Ammonia 3M)

Figure 5-23 shows the gold extraction in gold leaching with pre-conditioning operation. With 24 hours pre-conditioning and leaching, the gold extractions were 67% and 61.93% respectively for Hope Brookeee ore and M ore. The gold extraction was increased to 76.05% in a solution pre-conditioned for 72 hours with EDTA addition in the leaching stage.

Dissolved copper was measured before and after gold leaching process.

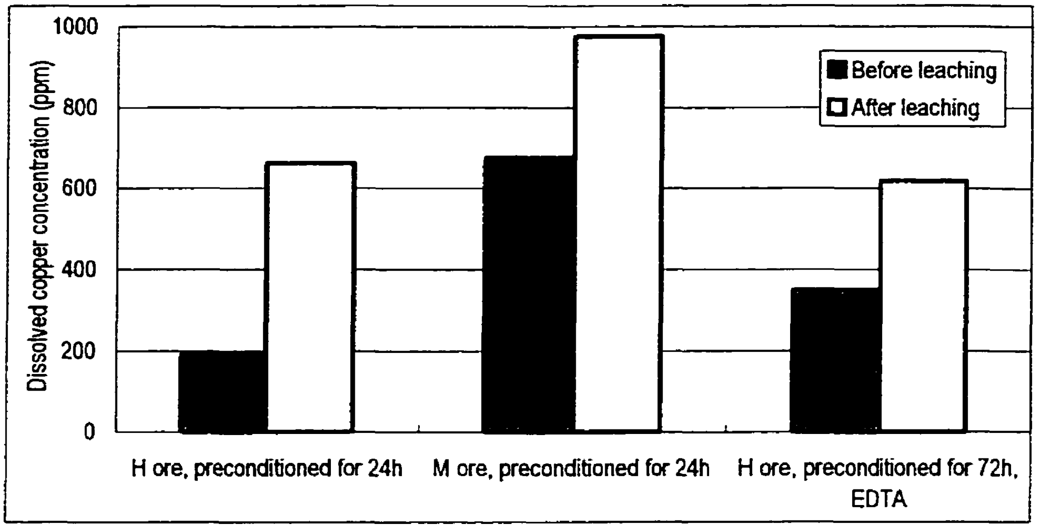

Figure 5-24 Dissolved Copper Before and After Gold Leaching in Pre-conditioning Tests

(Thiosulphate 0.3M, Ammonia 3M)

Figure 5-24 shows the copper concentration before and after thiosulphate leaching. The copper concentration before leaching represents the amount of copper dissolved by ammonia. The increase of copper concentration after leaching represents the amount of copper dissolved mainly by thiosulphate.

5.2.3.4 Effect of Nickel Sulphate in "Non-copper" Gold Leaching Tests

Nickel sulphate was used as a catalyst for gold dissolution. Reagent concentrations are listed in the Table 5-7

Table 5-7 Reagent Conditions for Test Group "E-Ni"

Experiment No.	Ammonia (M)	Nickel Sulphate (M)
E-Ni-1	3	0.001
E-Ni-2	3	0.005
E-Ni-3	3	0.01
E-Ni-4	1	0.005
E-Ni-5	0.3	0.005

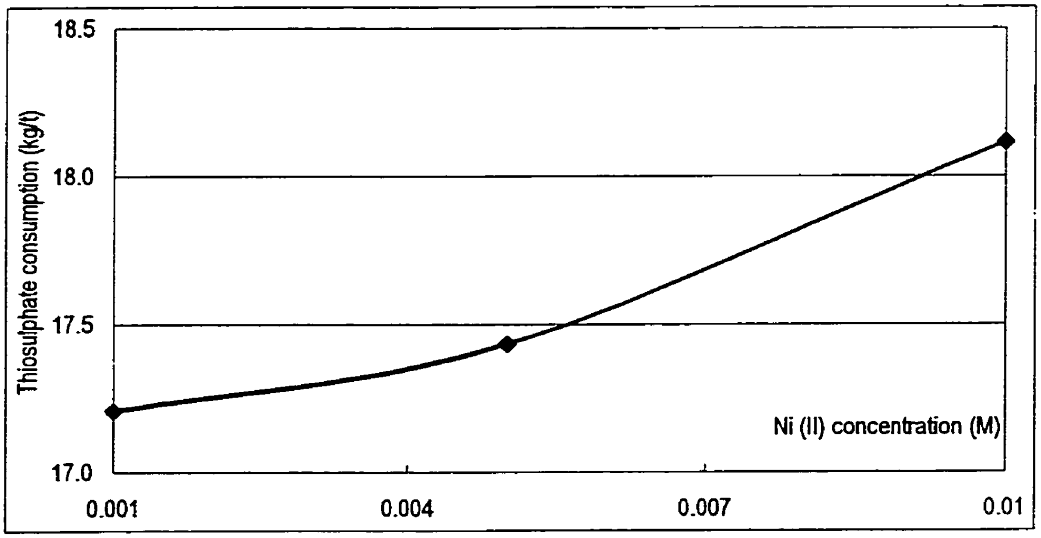

Figure 5-25 Effect of Nickel Sulphate Concentration on Thiosulphate Consumption (without Copper Sulphate)

(Thiosulphate 0.3M, Ammonia 3M)

Figure 5-25 shows that the thiosulphate was less stable in a solution containing ammonia concentration less than 1M. Figure 5-41 shows that the thiosulphate consumption was reduced from 18.11 kg/t to 17.21 kg/t as the nickel concentration was decreased from 0.01M to 0.001M.

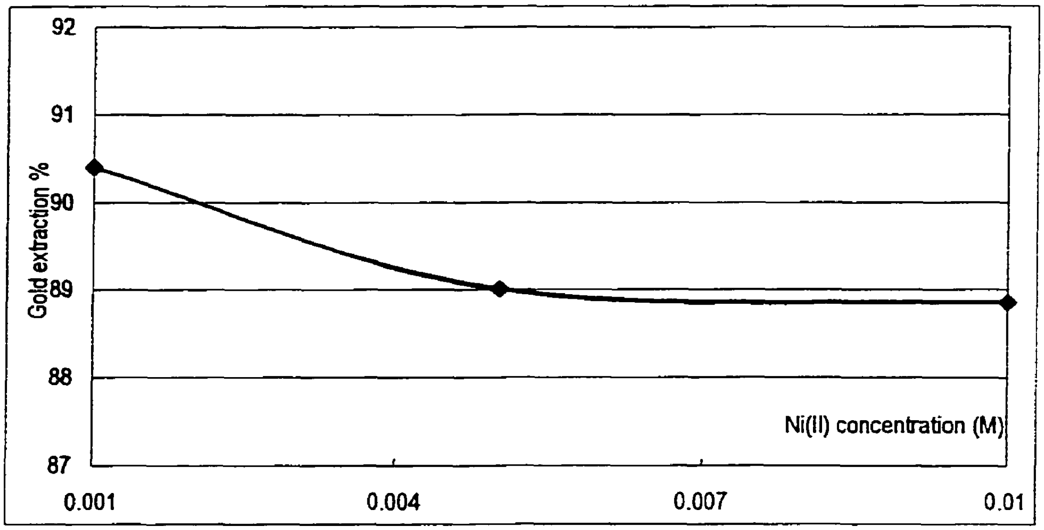

Figure 5-26 Effect of Nickel Sulphate Concentration on Gold Extraction (without Copper Sulphate)

(Thiosulphate 0.3M, Ammonia 3M)

Figure 5-26 shows that lower concentration of nickel sulphate was preferred for a higher gold extraction. When nickel sulphate concentration was increased from 0.001M to 0.01M, the gold extraction was reduced from 90.4% to 88.85%. This result demonstrates that nickel sulphate might replace copper sulphate in the leaching of copper-bearing sulphide gold ore.

The effect of ammonia concentration on thiosulphate consumption and gold extraction in nickel catalysed gold leaching will be discussed as follows.

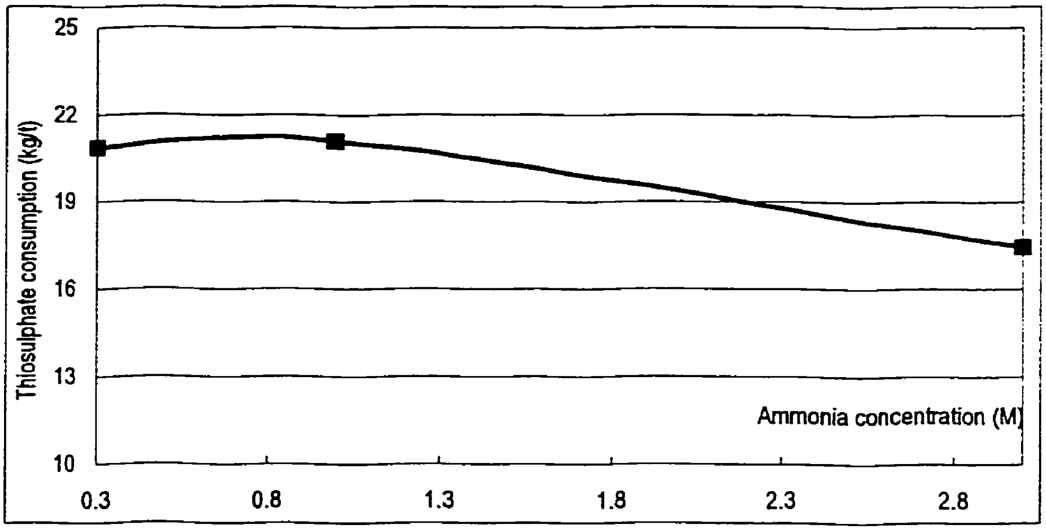

Figure 5-27 Effect of Ammonia Concentration on Thiosulphate Consumption in Nickel-catalysed Gold Leaching

(Thiosulphate 0.3M, Nickel sulphate 0.005M)

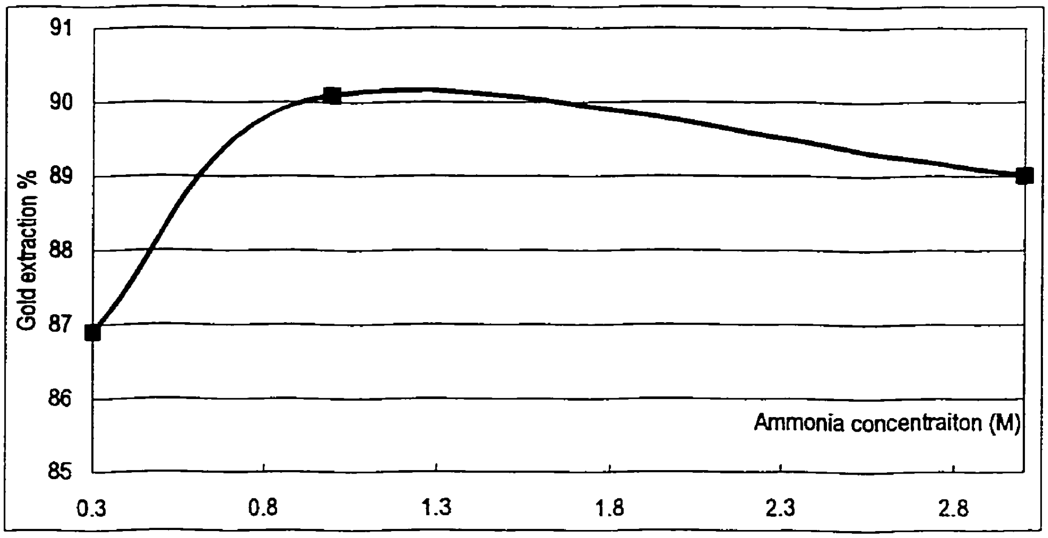

Figure 5-28 Effect of Ammonia Concentration on Gold Extraction in Nickel-catalysed Gold Leaching

(Thiosulphate 0.3M, Nickel sulphate 0.005M)

Figure 5-27 shows that thiosulphate consumption was reduced from 20.83kg/t to 17.43 kg/t by increasing the concentration of ammonia from 0.3M to 3M. Figure 5-28 shows that ammonia concentration at 1M to 3M produced a better gold extraction. The best gold extraction was 90.09% when ammonia concentration was 1M. When the ammonia concentration was 0.3M, the gold extraction was reduced to 85.9%. The gold extraction was 89% when ammonia concentration was 3M.

5.3 Effects of Thiosulphate Concentration

Thiosulphate concentration is a major factor affecting gold dissolution. At the same time, thiosulphate is one of the most important copper complexing agents. It was concluded from the thiosulphate solution decomposition test results that a lower thiosulphate concentration is preferred to save thiosulphate reagent. Thus, the effort was focused on reducing the thiosulphate concentration.

5.3.1 Effects of Thiosulphate Initial Concentration

In this series of tests, thiosulphate concentrations ranging from 0.15M to 0.45M were studied.

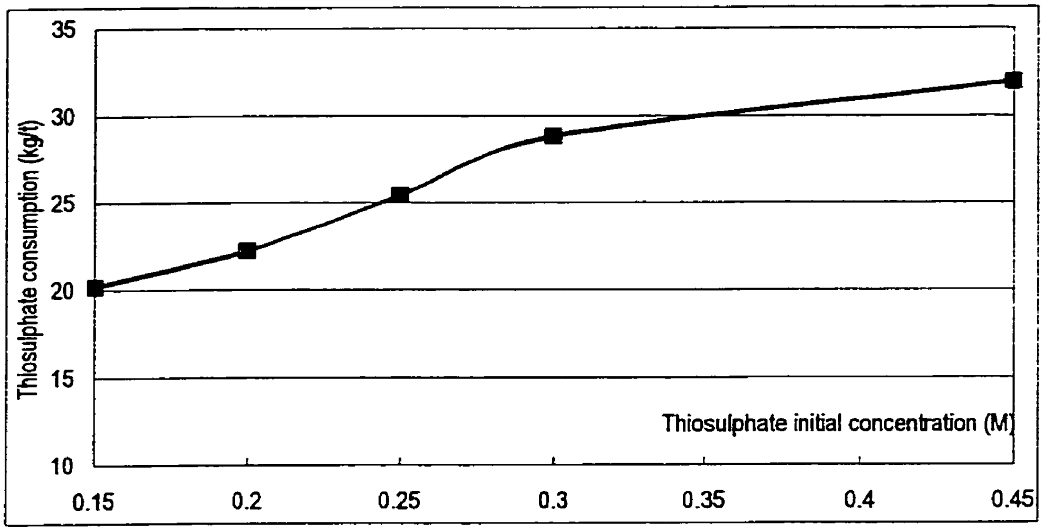

Figure 5-29 Effect of Thiosulphate Initial Concentration on Thiosulphate Consumption

(Copper sulphate 0.03M, Ammonia 3M)

Figure 5-29 shows that thiosulphate consumption was increased from 20.16kg/t to 31.93kg/t as the thiosulphate initial concentration was increased from 0.15M to 0.45M.

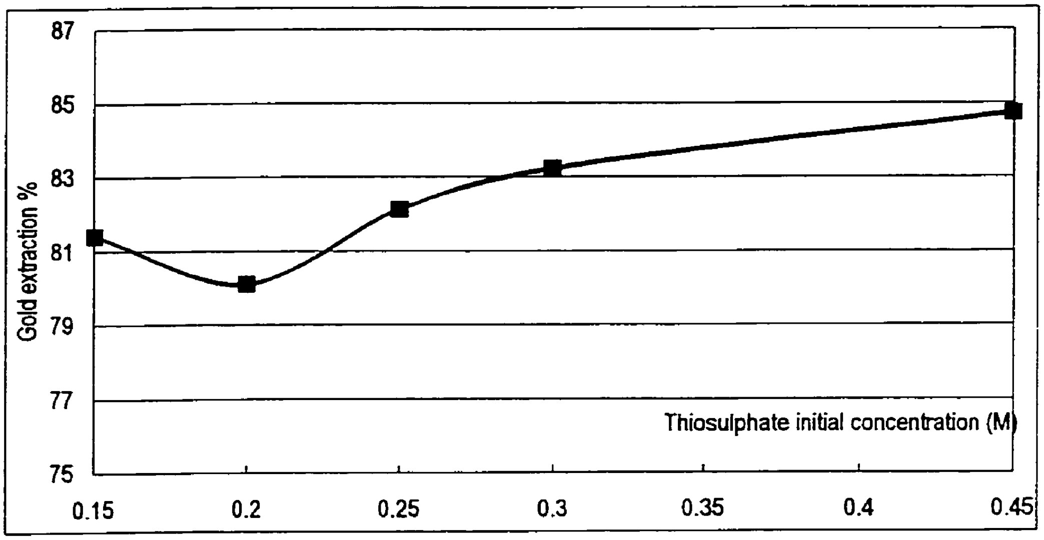

Figure 5-30 Effect Of Thiosulphate Initial Concentration On Gold Extraction

(Copper sulphate 0.03M, Ammonia 3M)

Figure 5-30 shows that with a decrease of thiosulphate initial concentration from 0.45M to 0.15M, gold extraction was reduced from 84.71% to 80.09% and 81.4%.

5.3.2 Gold Leaching at Low Thiosulphate Concentration

The solutions contained 0.15M thiosulphate, 0.0005M of copper sulphate and 0.1M ~ 0.3M ammonia. The leaching time was extended to 48 hours. Air was replenished at the 8th and 24th hour. Solution pH was adjusted to 9.9 with lime.

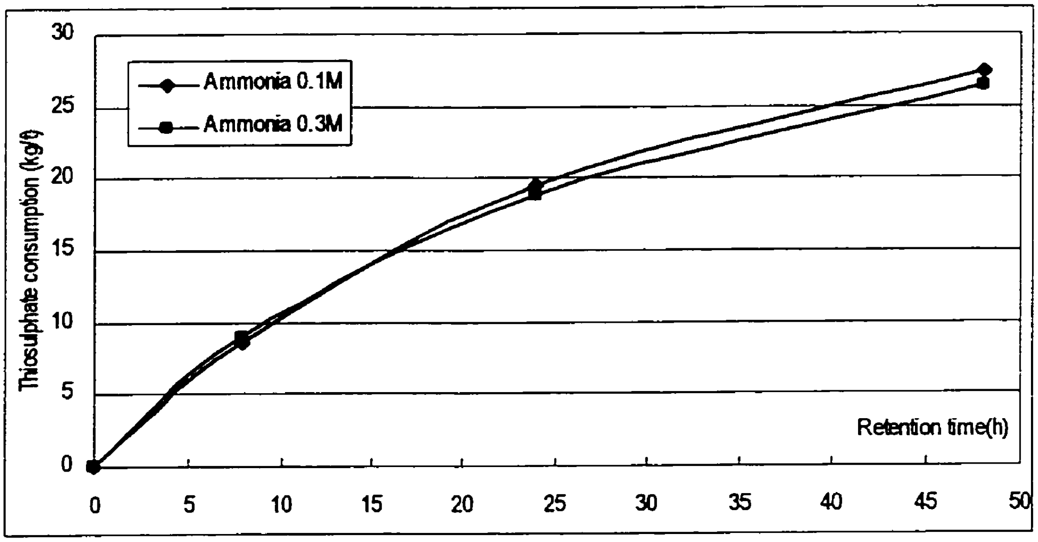

Figure 5-31 Effect Of Low Reagent Strength Leaching On Thiosulphate Decomposition Curves

(Duration time 48h, Solution pH 9.9, Thiosulphate 0.15M Copper sulphate 0.0005M)

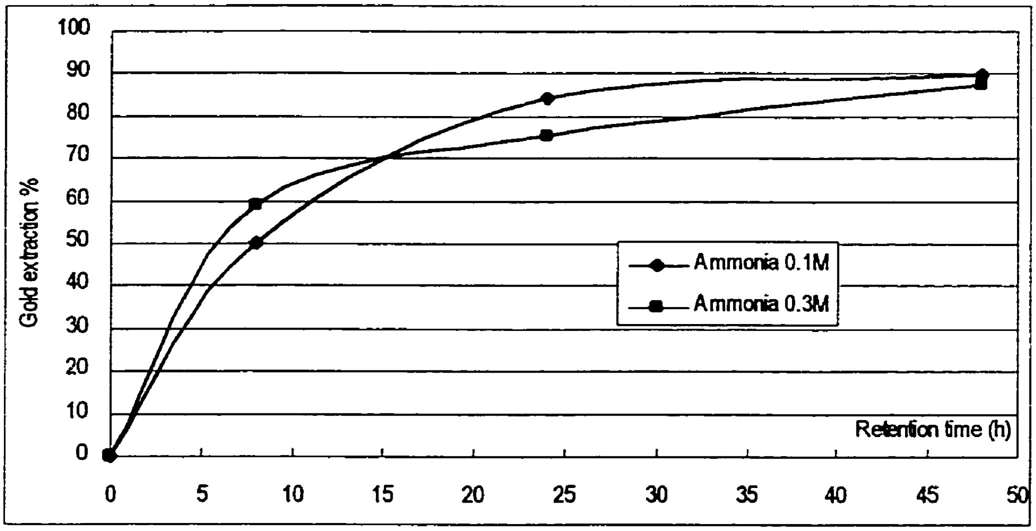

Figure 5-32 Effect of Low Reagent Strength Leaching on Gold Extraction
(Duration time 48h, Solution pH 9.9, Thiosulphate 0.15M Copper sulphate 0.0005M)

Figure 5-31 shows that thiosulphate consumption was about 19kg/t at the 24th hours and 28kg/t at the 48th hour. No difference in thiosulphate consumption per ton of ore by adding 0.1M or 0.3M of ammonia was realized.

Figure 5-32 shows that gold extraction was about 88% in 48 hours. This acceptable gold extraction percentage demonstrates the possibility of low reagent strength leaching. However, the gold dissolution rates were slightly slower than that of the high reagent strength solution. Only 75 to 84% of gold was extracted in 24 hours.

5.4 Effect of Sulphur Compounds as Additives

The effect of sulphur compounds on the thiosulphate stability has been studied. In this series of studies, the effect of sulphur compounds including sulphite, sulphate and thiosulphate on the thiosulphate consumption and gold extraction was investigated.

5.4.1 Effects of Sodium Sulphite

The effect of sulphite concentration on thiosulphate consumption and gold extraction was studied in the range of 0M to 0.2M.

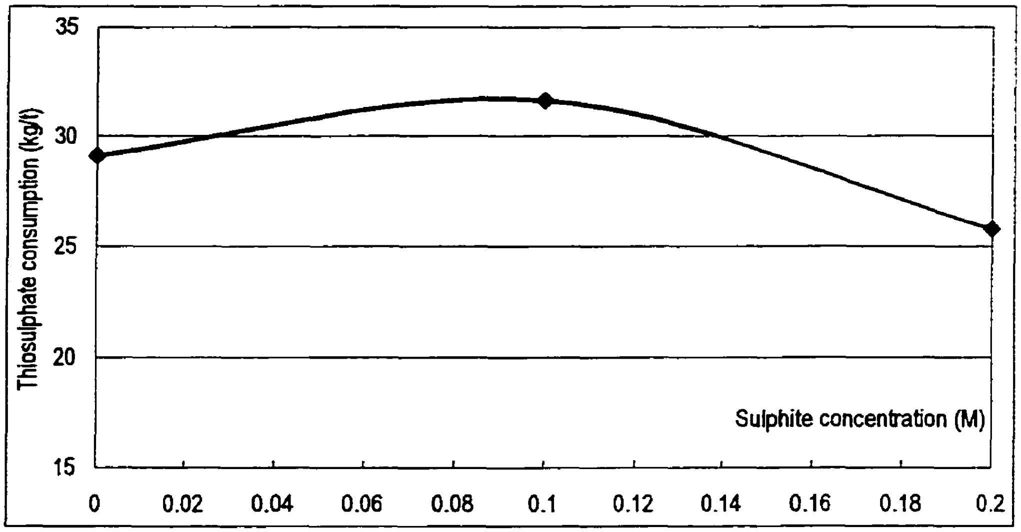

Figure 5-33 Effect of Sulphite Concentration on Thiosulphate Consumption
(Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M)

Figure 5-33 shows that the addition of sulphite at 0.1M did not improve the stability of thiosulphate. The maximum thiosulphate consumption (31.64 kg/t) appeared in a solution containing 0.1M of sulphite. When the sulphite concentration increased to 0.2M, the thiosulphate stability was improved. At the 4th hour, 7% more thiosulphate remained as compared with the non-sulphite additive. At the 24th hour, the improvement increased to about 10%. The thiosulphate condition was reduced from 29.07kg/t to 25.73 kg/t.

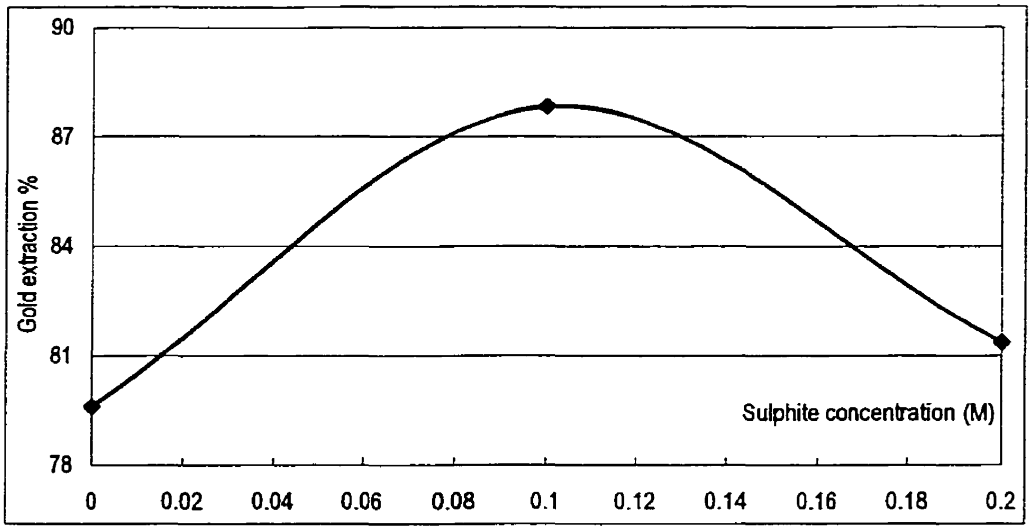

Figure 5-34 Effect of Sulphite Concentration on Gold Extraction
(Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M)

Figure 5-34 shows that the addition of sulphite increased the gold extraction from 79.59% to 87.82% when the sulphite concentration was increased from 0M to 0.1M. A further increase of sulphite concentration to 0.2M reduced the gold extraction to 81.34%.

5.4.2 Effects of Sodium Sulphate

In this series of tests, sodium sulphate was used as the source of sulphate anion.

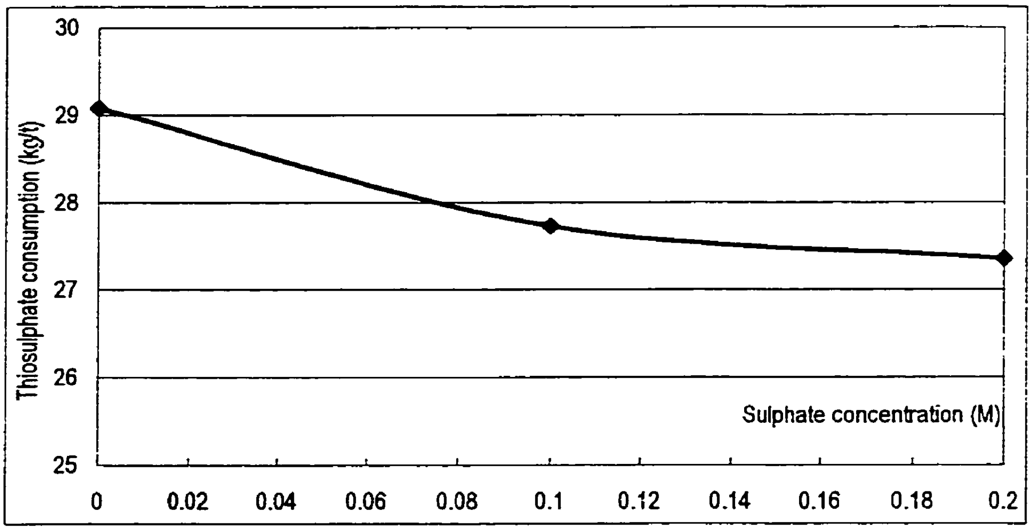

Figure 5-35 Effect of Sulphate Concentration on Thiosulphate Consumption
(Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M)

Figure 5-35 shows the effect of sulphate on thiosulphate stability. As the sulphate concentration increased from 0M to 0.2M, the thiosulphate consumption was slightly reduced from 29.07 kg/t to 27.35 kg/t. There was no difference in consumption for additions 0.1M and 0.2M sulphate.

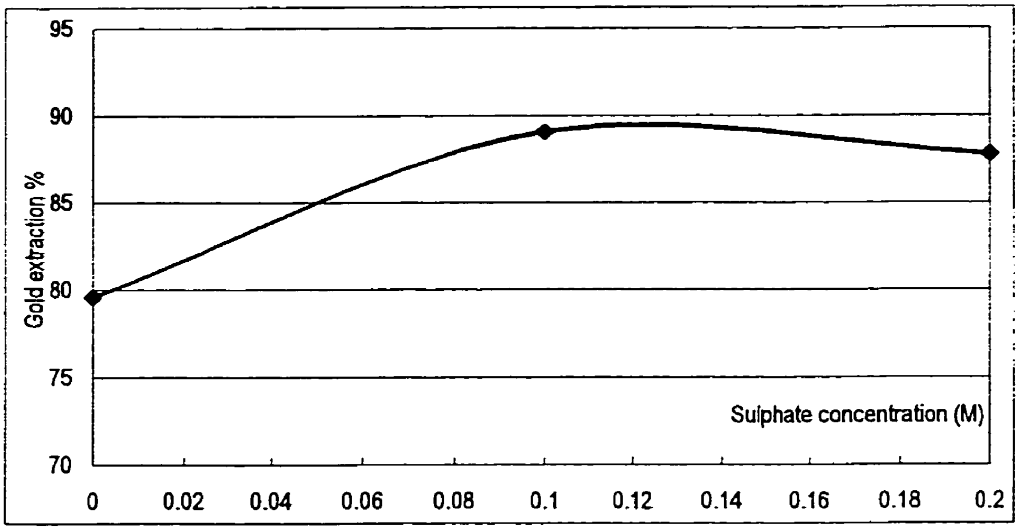

Figure 5-36 Effect of Sulphate Concentration on Gold Extraction
(Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M)

Figure 5-36 shows that the addition of sulphate improved the gold extraction from 79.6% to 89.02% when sulphate concentration was increased from 0M to 0.1M. When the sulphate concentration was 0.2M, the gold extraction was slightly decreased to 87.73%.

5.5 Effect of Pulp Density

The effect of pulp density on thiosulphate consumption and gold extraction was examined in a solution containing 0.15M ~ 0.3M thiosulphate, 0.1M to 0.3M ammonia and 0.0005M copper sulphate. The reagent concentration and pulp density are listed in Table 5-8.

Table 5-8 Operating Conditions for Test Group "E-Pulp"

Experiment No.	Thiosulphate (M)	Ammonia (M)	Pulp Density (% Solid)
E-Pulp-1	0.15	0.10	61.54

E-Pulp-2	0.30	0.30	61.54
E-Pulp-3	0.30	0.30	54.55
E-Pulp-4	0.30	0.30	44.44
E-Pulp-5	0.30	0.30	28.57

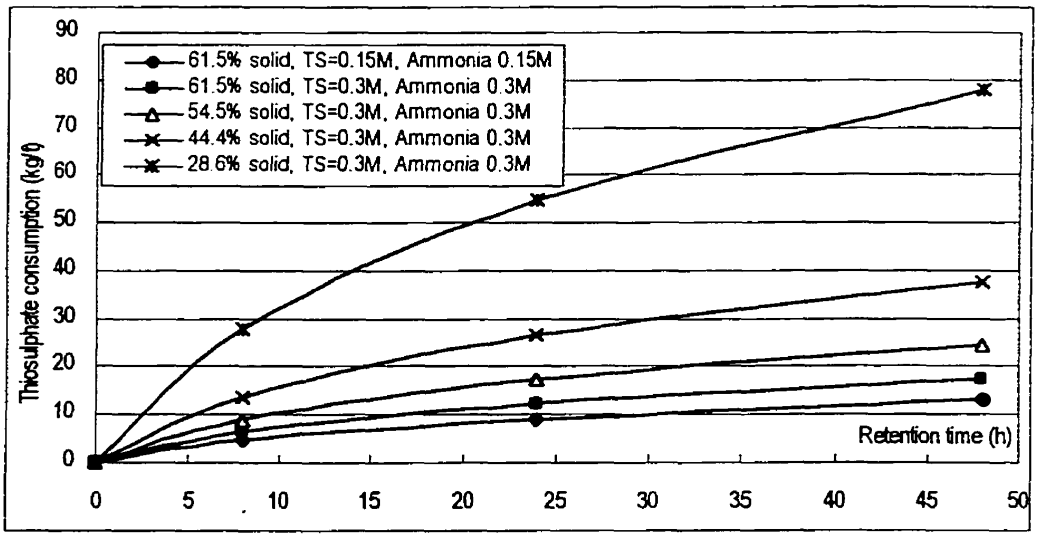

Figure 5-37 Effect of Pulp Density on Thiosulphate Consumption (kg/t)
(Solution pH 9.9, Duration time 48h, Air refreshing at 8th, 24th hour, Copper sulphate 0.0005M)

Figure 5-37 shows that the increase of pulp density might reduce the thiosulphate consumption (kg/t). When the pulp density was increased from 28.6% to 61.5% the thiosulphate consumption at the 48th hour was reduced form 77.9 kg/t to 17.35 kg/t. The consumption of thiosulphate in the solution containing 0.15M of thiosulphate and 0.1M of ammonia was better than the solution containing 0.3M thiosulphate and 0.3M of ammonia. The lowest consumption, at the 48th hour, was 13.05kg/t under the conditions of 0.15M thiosulphate, 0.1M ammonia and 61.54% solid.

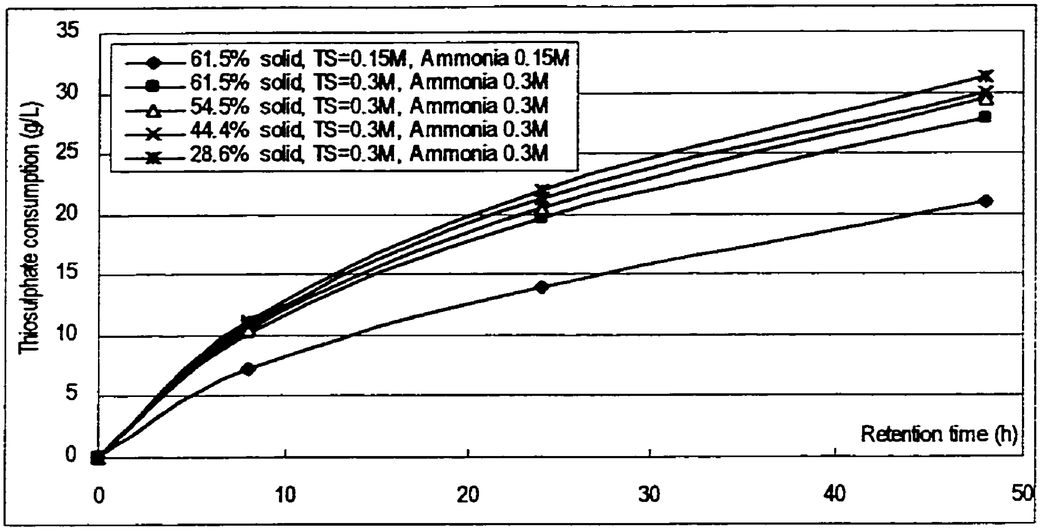

Figure 5-38 Effect Pulp Density on Thiosulphate Consumption (g/L)
(Solution pH 9.9, Duration time 48h, Air refreshing at 8th, 24th hour, Copper sulphate 0.0005M)

Figure 5-38 shows the effect of pulp density on thiosulphate consumption per litre of leaching solution. As the pulp density was increased from 28.6% to 61.5% in the solutions containing 0.3M of thiosulphate, the consumption per unit volume of solution was actually reduced slightly from 31.16 g/L to 27.76 g/L at the 48th hour. The decrease of thiosulphate initial concentration from 0.3M to 0.15M reduced the consumption from 27.76 g/L to 20.88 g/L.

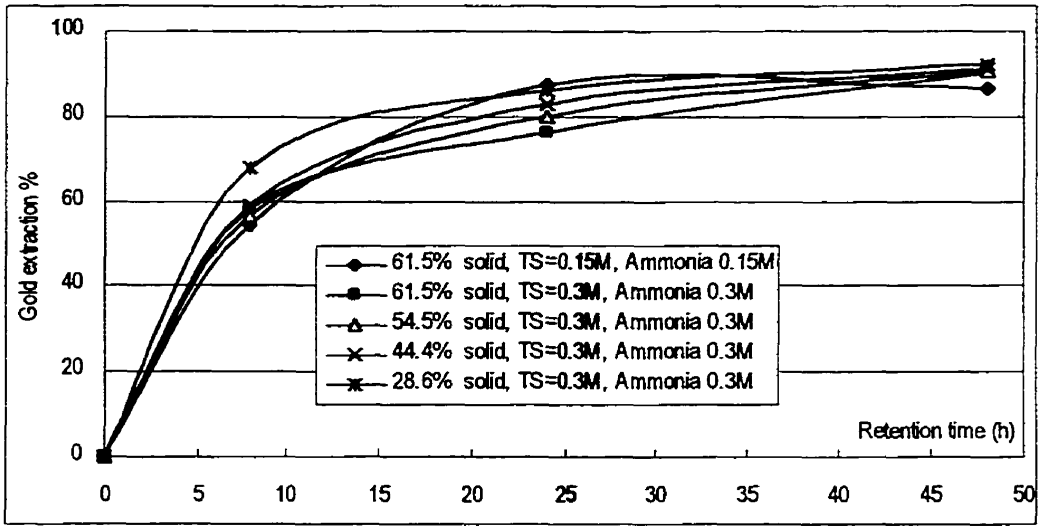

Figure 5-39 Effect of Pulp Density on Gold Extraction

(Solution pH 9.9, Duration time 48h, Air refreshing at 8th, 24th hour, Copper sulphate 0.0005M)

Figure 5-39 shows that gold extraction was not influenced significantly by the changes of pulp density. After 48 hours leaching, gold extraction was in the range of 86% to 91%. The decrease of pulp density from 61.5% to 28.6% solids reduced the gold extraction slightly from 91.91 to 90.01%. The decrease of thiosulphate and ammonia concentration to 0.15M and 0.1M led to a lower gold extraction at 86.51%.

5.6 Effect of Ore Characteristics

Gold ore samples usually contain different oxide and sulphide constituents, which may react with chemical compounds of the lixiviant and cause different reagent consumption and gold extraction. This series of tests was designed to study the effect of FeO, $CuFeS_2$ and roasting on the thiosulphate consumption and gold extraction. Details of conditions are listed in Table 5-9. All additional minerals were 100% minus 200mesh. Roasting operation of Hope Brookeee ore was carried out at 650 °C in a furnace. 300 grams of ground ore sample was filled into an open iron vessel. The ore sample was stirred every 15 minutes in the 60 minute roasting procedure. The roasted ore sample was quenched in water and dried for leach testing.

Table 5-9 Operating Conditions for Test Group "E-Ore"

No.	Ore (g)	Add FeO (g)	Add $CuFeS_2$ (g)	Roast
E-Ore-1	200	0	0	No
E-Ore-2	160	40	0	No
E-Ore-3	200	0	0	60min total, 650 °C
E-Ore-4	160	0	40	No

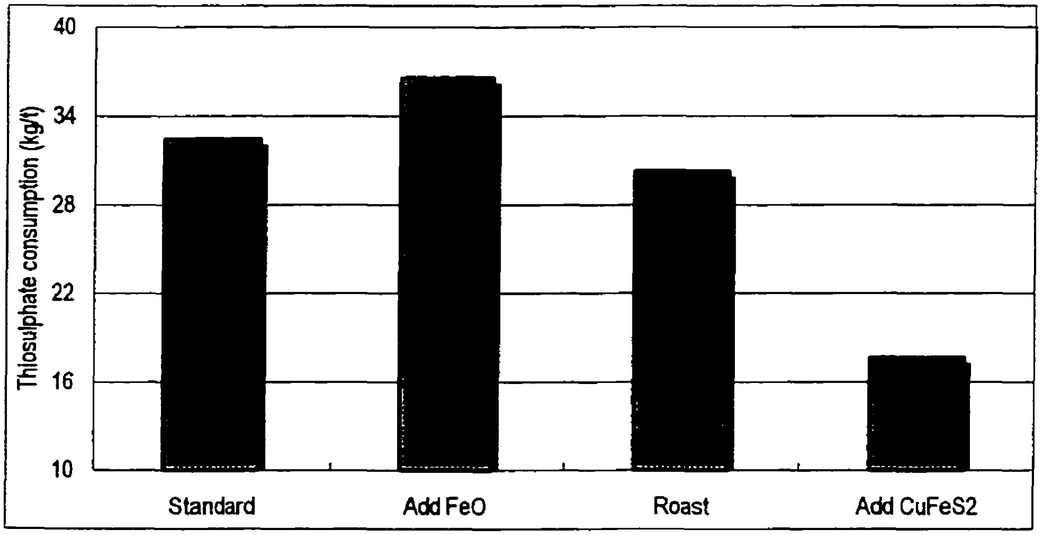

Figure 5-40 Effect of Mineral Contents on Thiosulphate Consumption
(Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M)

Figure 5-40 shows that the thiosulphate consumption of the sample having FeO addition was 4 kg/t higher than that of the original sample (32.37kg/t). The roasting operation helps to save 2 kg/t. The addition of chalcopyrite reduced thiosulphate consumption by 15 kg/t. at the 24th hour. After zinc precipitation, the thiosulphate consumptions were reduced. In the solution with chalcopyrite addition, the restoration of thiosulphate was about 3.5 kg/t. In the roasted sample, the restored thiosulphate was 4.5 kg/t. In the original ore sample, the restored thiosulphate was 5.4 kg/t. In the solution with ferrous oxide addition, the restored thiosulphate reached 7.8 kg/t.

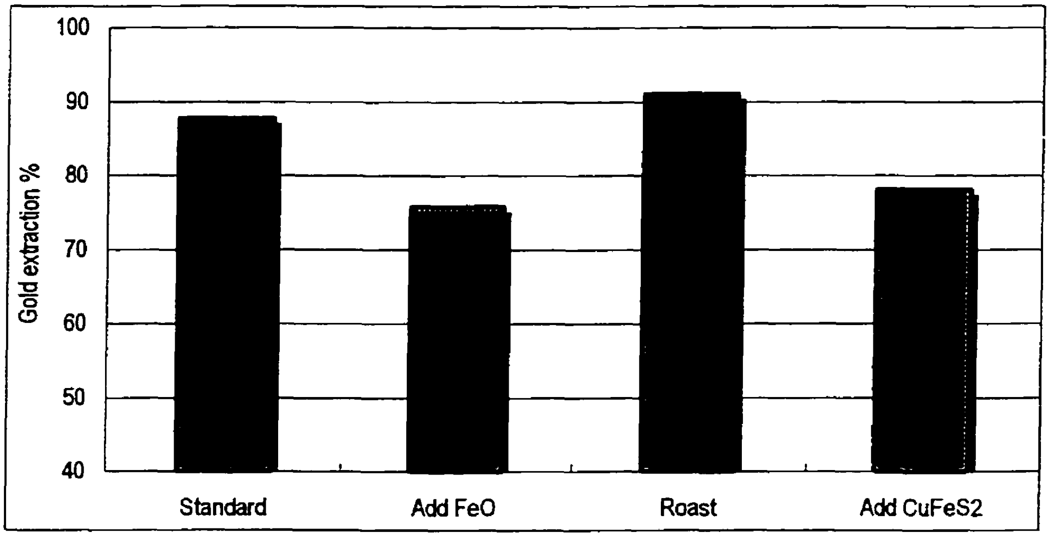

Figure 5-41 Effect of Mineral Properties on Gold Extraction
(Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M)

Figure 5-41 shows that the addition of ferrous sulphite and chalcopyrite reduced gold extraction from 87.7% to 75.69% and 78.02%. The roasting operation increased gold extraction to 91.03%.

This group of tests was only an initial investigation in this area. More tests should be done to explore how the mineral properties influence thiosulphate stability and gold extraction.

5.7 Effect of Oxygen

Oxygen is the driving force of oxidation reactions for both gold extraction and thiosulphate decomposition. The amount of dissolved oxygen in solution controlled the extent of the oxidation reactions. In Eh-pH diagrams, the dissolved oxygen content influences the potential level and moves the leaching area upwards or downwards. Sulphite additives might also be affected by the oxygen supply condition. Thus, the oxygen supply methods and strength were studied in the following tests to explore the effect of oxygen.

5.7.1 Gold Leaching in Open-Vessel and Closed-Vessel

There are two methods for oxygen supply into the leaching solution: the open-vessel operation method and the closed-vessel operation method. Sparging airflow and oxygen flow can enrich oxygen in solution. On the contrary, sparging nitrogen flow and sulphur dioxide gas can lower the oxygen level. The testing conditions are listed in Table 5-10.

Table 5-10 Operating Conditions for Test Group "E-Air"

Experiment No.	Oxygen supply methods	EDTA (M)
E-Air-1	Air in a capped bottle	0
E-Air-2	Air in a capped bottle	0.03
E-Air-3	Open air	0
E-Air-4	Open air	0.03

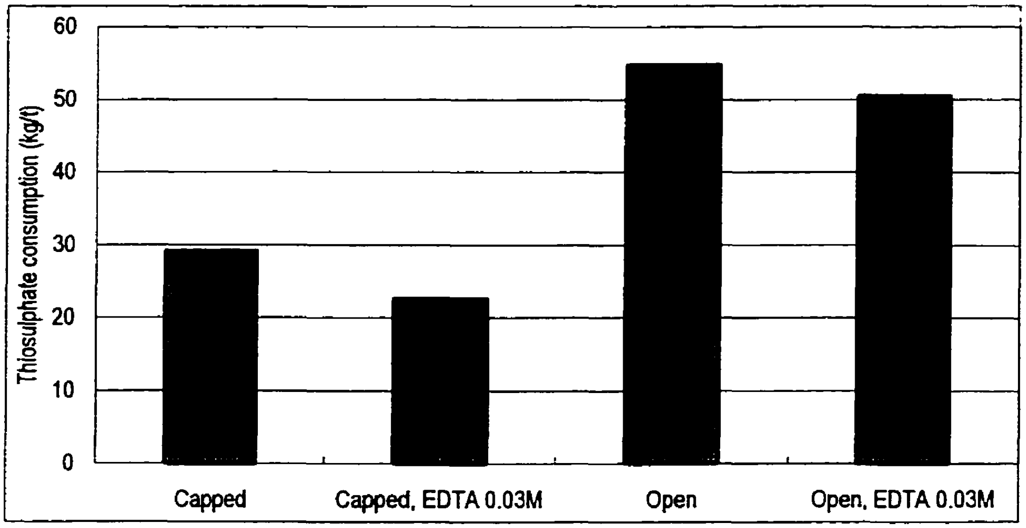

Figure 5-42 Effect of Oxygen Supply Methods on Thiosulphate Consumption
(Thiosulphate 0.25M, Ammonia 3M, Copper sulphate 0.03M)

Figure 5-42 shows that more thiosulphate was consumed in open-vessel than in closed-vessel tests. In the capped bottle, 29.07 kg/t of thiosulphate was consumed in 24 hours. In the open-vessel test, the thiosulphate consumption was 55.66 kg/t more. The addition of EDTA reduced the thiosulphate consumption by about 7 kg/t in the capped bottle and 4 kg/t in the open bottle.

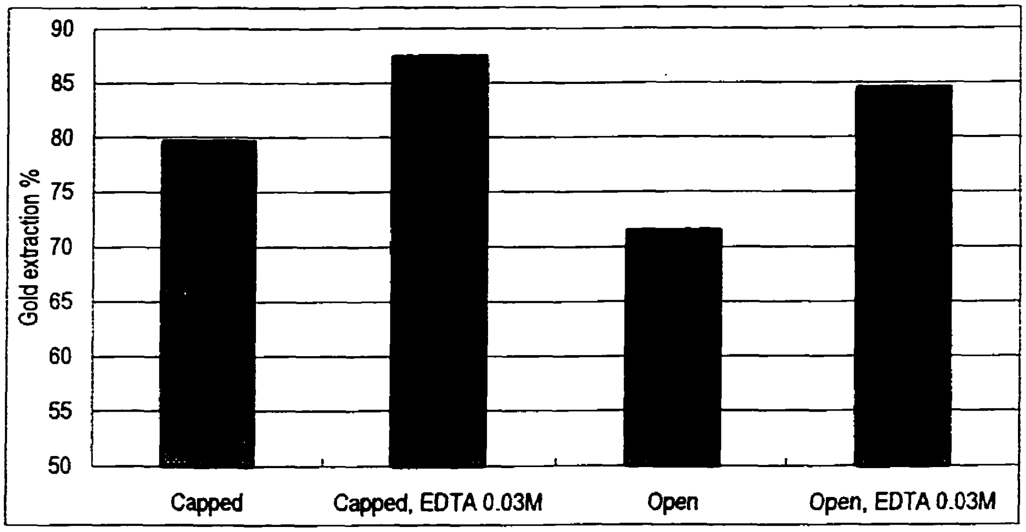

Figure 5-43 Effect of Oxygen Supply Methods on Gold Extraction
(Thiosulphate 0.25M, Ammonia 3M, Copper sulphate 0.03M)

Figure 5-43 shows the effect of open and capped bottle tests on gold extraction. 79.59% of gold was extracted in a capped bottle in 24 hours. EDTA addition in a capped bottle test improved the gold extraction to 87.88%. In the open bottle test, 97.6% of thiosulphate was consumed. Thus the gold extraction was 71.4% only. By adding EDTA into the open bottle, the gold extraction was increased to 84.49%.

5.7.2 Effects of Deoxygenating Operation in Gold Leaching

De-oxygenating was conducted by sparging nitrogen gas into the lixiviant. The amount of dissolved oxygen was not measured. Instead, the flow rate of nitrogen gas was recorded. It is believed that the nitrogen flow rate is inversely proportional to the dissolved oxygen amount.

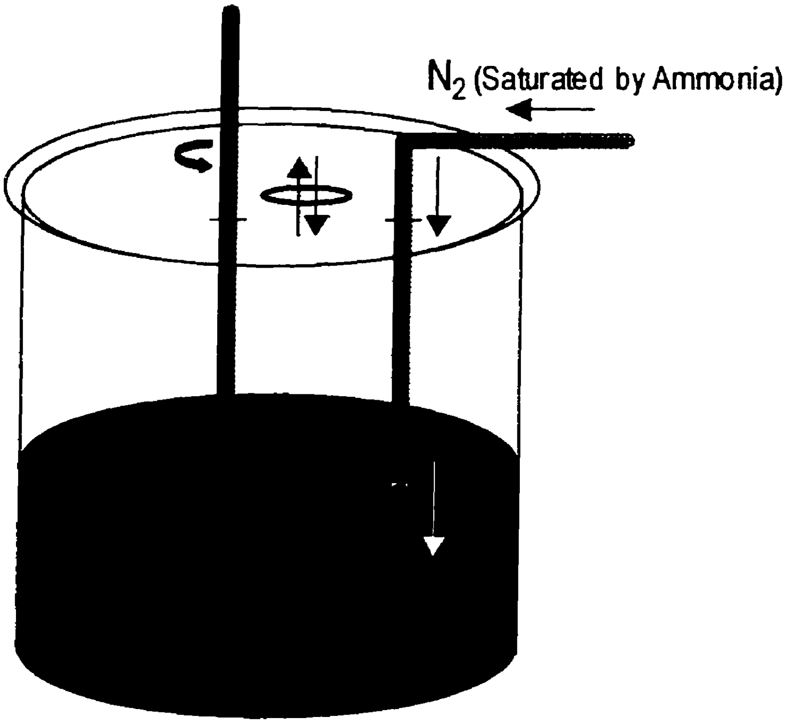

Figure 5-44 Apparatus for Gold Leaching with Nitrogen Flow

As shown in Figure 5-44, the experiments were carried out in 500ml beakers with a mechanical stirrer. Nitrogen gas was pre-saturated by ammonia solution, measured by a flow meter and pumped into solutions. The pulp was pre-conditioned by nitrogen flow for several hours until the oxygen level was stable. Reagents were then added into solution to start gold leaching. The loss of water and ammonia was replenished during the process. Duration time for leaching was 8 hours. The nitrogen flow rate and stirring speed were kept constant all the time.

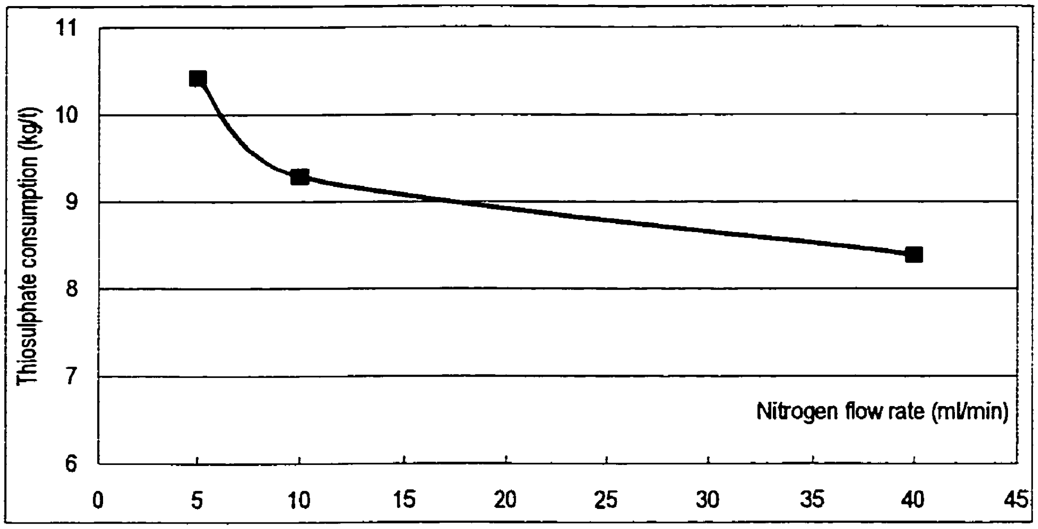

Figure 5-45 Effect of Nitrogen Flow Rate on Thiosulphate Consumption
(Duration time 8h, Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M)

Figure 5-45 shows that the application of nitrogen flow significantly reduced the thiosulphate consumption. After 8 hours leaching, the thiosulphate consumption ranged from 10.4 kg/t at 5 ml/min to 8.4 kg/t at 40 ml/min. After zinc precipitation, the thiosulphate consumption was 5.2 kg/t at nitrogen flow rate of 5 ml/min and 4.1 kg/t at nitrogen flow rate of 40 ml/min.

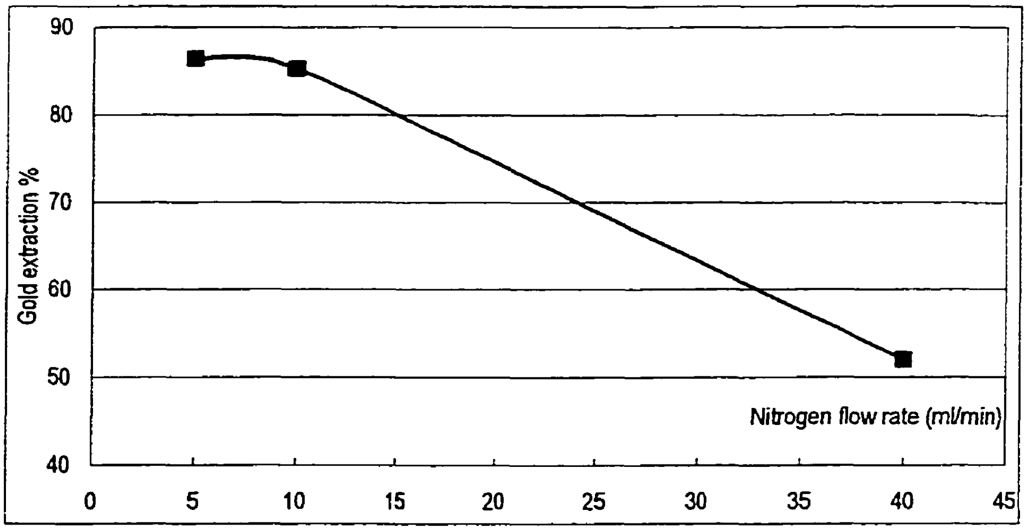

Figure 5-46 Effect of Nitrogen Flow Rate on Gold Extraction

(Duration time 8h, Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M)

Figure 5-46 shows the effect of nitrogen flow rate on gold extraction. At nitrogen flow rates of 5ml/min and 10ml/min, the gold extraction was 86.38% and 85.23% respectively. As the nitrogen flow rate was increased to 40ml/min, the gold extraction was 51.99%. The reason is the lack of oxygen supply in the solution.

5.8 Effect of Zinc Precipitation on Thiosulphate Regeneration

As mentioned in previous tests, thiosulphate was restored after the addition of zinc powder. This result is so interesting that it can help us to explore the chemistry of thiosulphate decomposition. At the same time, the investigation of the zinc precipitation process is valuable for gold recovery.

Zinc powder was applied to the pregnant solutions. The pregnant solution contained 2.08mg/L gold. The thiosulphate concentration of the pregnant solution was 0.204M. Zinc powder amount and zinc precipitation time were studied according to the conditions listed in Table 5-11

Table 5-11 Zinc Amount and Precipitation Time for Test Group "E-Zn1"

Test No.	Zn (g/L)	Time (min)
E-Zn-1	3.12	0
E-Zn-2	3.12	7
E-Zn-3	3.12	15
E-Zn-4	3.12	30
E-Zn-5	3.12	60
E-Zn-6	6.25	0
E-Zn-7	6.25	7
E-Zn-8	6.25	15
E-Zn-9	6.25	30
Zn-10	6.25	60
Zn-11	9.37	0
Zn-12	9.37	7
Zn-13	9.37	15
Zn-14	9.37	30
Zn-15	9.37	60
Zn-16	12.50	0
Zn-17	12.50	7
Zn-18	12.50	15
Zn-19	12.50	30
Zn-20	12.50	60

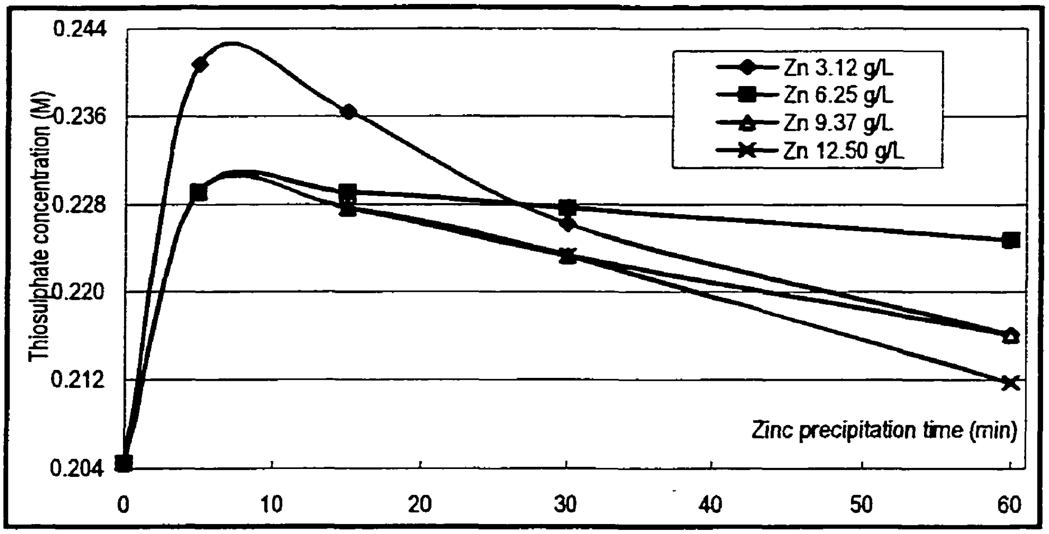

Figure 5-47 Thiosulphate Regeneration Curves in Zinc Precipitation Process

Figure 5-47 shows the effect of zinc powder amount on the thiosulphate restoration. Within the first 7 minutes after addition of zinc powder, thiosulphate concentrations increased from 0.204M to 0.229M (3.12g/L zinc) and 0.241M (6.25g/L to 9.37g/L zinc) with thiosulphate restoration of 12.1% and 0.82% respectively. After that, the restored thiosulphate started to decompose. At the 60th minute, the net amount of thiosulphate restoration was only 3.9% to 6.8%. From the shape of the curves shown in Figure 5-69, the maximum thiosulphate concentration was reached at or before the 7th minute. This is an indication that the restoration of thiosulphate might be a very rapid reaction. After the first several minutes, the restored thiosulphate started to decompose again. The fastest decomposition occurred in the solution with 3.12 g/L of zinc addition. The excessive addition of zinc (9.37g/L and 12.50g/L zinc) decomposed thiosulphate fast as well. When a sufficient amount of zinc was added, the restored thiosulphate demonstrated the best stability. There was almost no decomposition from 7 to 60 minutes in this sample solution.

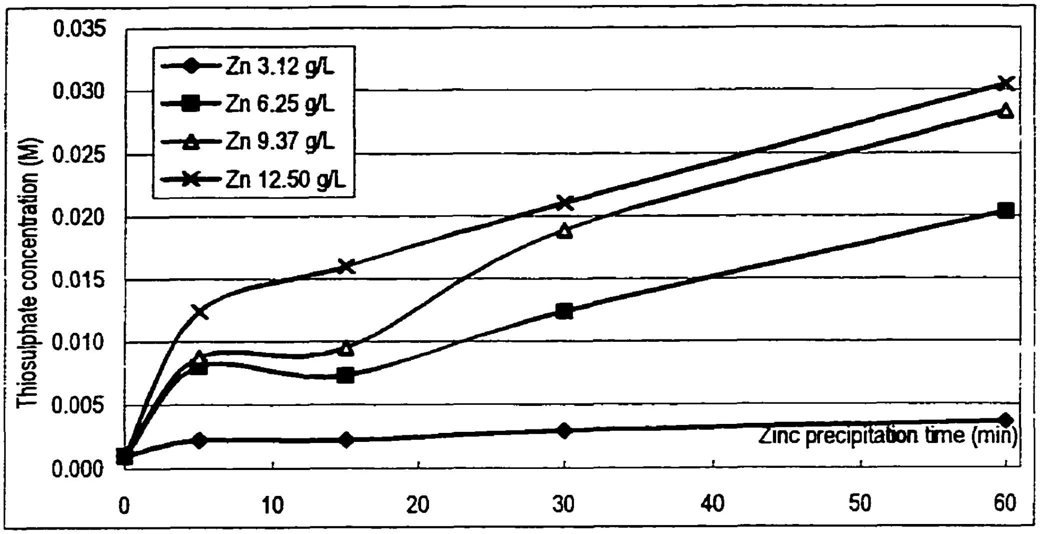

Figure 5-48 Sulphite Generation Curves in Zinc Precipitation Process

Figure 5-48 shows that sulphite is one of the products of thiosulphate decomposition after copper was precipitated by zinc powder. When the zinc amount was insufficient (3.12g/L), there was still active copper in the solution. The sulphite generation was very weak. Only 0.004M of sulphite was generated after 60 minutes. On the other hand, with a sufficient amount of zinc powder addition, the sulphite concentrations increased remarkably. The sulphite concentration was increased from 0.001M to 0.02M by 6.25g/L of zinc powder addition in 60 minutes. A further increase of zinc powder generated more sulphite.

Due to the importance of copper in thiosulphate regeneration and decomposition, the copper concentration was measured and listed in the following table (Table 5-12).

Table 5-12 Copper Concentration in Zinc Precipitation Process (mg/L)

Time (min)	Zinc (g/L)			
	3.12	6.25	9.37	12.50
7	22.30	1.90	2.71	1.21
15	23.08	3.08	1.78	2.26
30	33.21	3.59	2.20	1.33
60	500.00	1.87	2.44	4.95

Table 5-12 shows that copper concentration was reduced sharply by the addition of zinc powder. When the zinc amount was insufficient (3.12g/L), the copper concentration was higher than 20mg/L. When zinc was added in a sufficient amount (6.25g/L), the copper concentration decreased to lower than 3mg/L. A further addition of zinc powder (9.37g/L or 12.50g/L) could not further reduce the copper concentration. After 30 minutes, the solution with an insufficient amount of zinc powder began to extract copper back into the solution. The copper concentration reached 500mg/L after 60 minutes.

Results demonstrated that zinc powder addition in an insufficient amount couldn't completely precipitate the dissolved copper because the reactions might be stopped when the active surfaces of zinc powder were covered completely by precipitated gold and copper. Even more, the precipitated copper might be extracted back to solution after 60 minutes. On the other hand, sufficient and excessive amounts of zinc powder supplied enough active surfaces for the precipitation reactions. Most gold and copper contents might be precipitated in this case. The excessive supply of active zinc surfaces prevents the precipitated copper from dissolution again.

6. Discussion

6.1 Development of Thiosulphate Decomposition Chemistry

The chemistry of thiosulphate decomposition was briefly discussed in Chapter 2. There was no definite conclusion regarding the possible reactions, decomposition products and the effective stabilizers. Some researchers suggested various approaches concerning the effect of additives, such as sulphite and sulphate. However, there were no significant breakthroughs for the industrial application. The problem was that there were not many researchers systematically looking into the details of thiosulphate decomposition chemistry. The decomposition products of thiosulphate were not clearly defined as well.

Recently, Aylmore and Muir (2001) studied the S-H_2O system by thermodynamic analysis (Eh-pH diagrams) and defined that sulphite and trithionate are supposed to be the products of decomposed thiosulphate. Trithionate is supposed to be a stable species in this system. However, from this investigation (details in chapter 4 and 5), it was found that tetrathionate appears to be the most important primary product, which was not mentioned by Aylmore and Muir (2001). The reason for this difference may be due to the ignorance of copper's catalysis function on the complicated sulphur compound system. As shown in Figure 2-7, the influences of copper species on the Eh-pH diagram of the S-H_2O system were not defined.

The influences of metal catalysts were mentioned by Latimer (1952) in his discussion about the generation of tetrathionate. The reaction mechanism was doubtless complicated.

The redox couples formed by the addition of metal ion catalysts or the presence of electrodes were claimed to affect the formation of tetrathionate significantly.

Due to the difficulties in the tetrathionate measurement by laboratorial method, there was no direct evidence for the presence of tetrathionate. But some indirect evidence was observed in this investigation, which demonstrated the existence of tetrathionate. Based on the observation of oxygen supply's effect on thiosulphate stability, it was concluded that thiosulphate decomposition is mainly an oxidation process. The observation of thiosulphate regeneration in zinc precipitation indicated that there is an oxidation product (hereafter called "X") in the oxidized thiosulphate solution, which is metastable in the presence of dissolved copper and gold and very unstable as the copper and gold was precipitated. Based on these observations, the following analysis will be helpful to find our the primary, metastable products, "X".

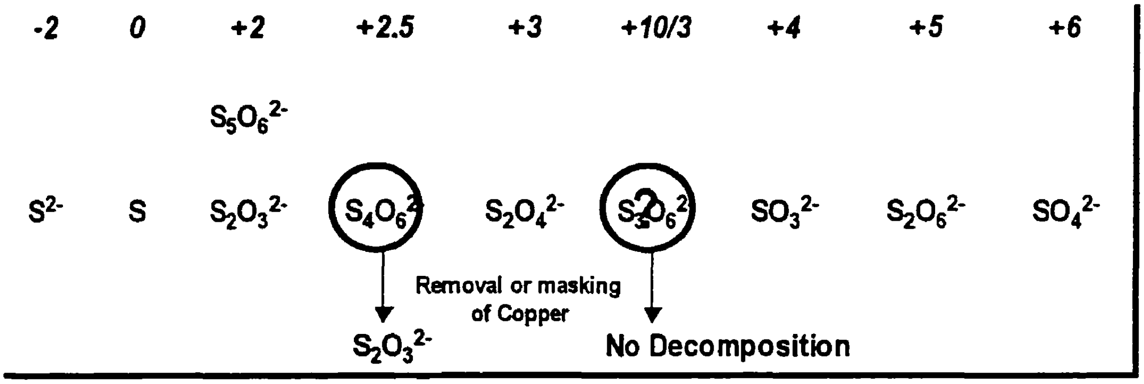

Figure 6-1 Sulphur Compounds in Aqua Solutions

A. There are at least 10 possible sulphur compounds in solution. They are listed in Figure 6-1. Those numbers above the names represent the valence of sulphur in these chemicals. So, sulphide anion, elemental sulphur and $S_5O_6^{2-}$

are not possible to be the primary, meta-stable oxidation product of thiosulphate decomposition. The results demonstrated that the sulphite concentration was very small before zinc precipitation. After zinc precipitation, both thiosulphate and sulphite concentrations increased remarkably. Thus, sulphite is not the source of thiosulphate regeneration. Sulphate, as a very stable sulphur compound, is not this metastable product, "X". $S_2O_4^{2-}$ and $S_2O_6^{2-}$ are described as strong reducing or oxidizing agent, which will be very difficult to co-exist with thiosulphate and dissolved oxygen in solution (Latimer, 1952).

B. As mentioned in the Eh-pH diagram of the sulphur-water system (Aylmore and Muir, 2001), trithionate is the predominant stable species under the leaching conditions (see Figure 2-7). So, trithionate may not decompose to thiosulphate and sulphite when the copper is precipitated by zinc. Thus, trithionate is also not this metastable product, "X".

C. It was claimed that tetrathionate is not stable in alkali solution without the interference of copper ion (Latimer, 1952). It was also concluded that certain redox couples brought by metal ions catalysts or surface electrodes enhance the production of tetrathionate. Copper ions may act as catalysts in gold leaching solution and make the tetrathionate a metastable anion in alkali solution. As copper ion, which is required for tetrathionate existence was removed from solution by zinc powder, tetrathionate might undergo a rapid decomposition to thiosulphate and sulphite. The study on tetrathionate stability in copper-ammonia solution demonstrated that tetrathionate decomposed to thiosulphate and sulphite gradually. The masking of copper significantly increased the generation of thiosulphate, which indicated that tetrathionate was a metastable species in the presence of copper. These characteristics of tetrathionate can be readily utilized to explain the thiosulphate decomposition and regeneration in the stage of gold leaching and zinc precipitation.

After the recognition of tetrathionate as the most possible primary metastable product of thiosulphate decomposition and oxidation, a series of reactions was developed to explain the mechanism and the procedure of thiosulphate decomposition.

Generally, there are two major types of reactions, complexing and oxidation, which occurred in the thiosulphate gold leaching solution. As a complex agent, thiosulphate might form gold and copper complexes in ammonia solution. The complexing process does not decompose and consume the thiosulphate. It was realized in this investigation that the major reason for the decomposition of thiosulphate is oxidation. Thiosulphate is a typical weak reducing agent and is not stable in a solution in the presence of oxygen. The evidence has shown that this oxidation reaction is catalysed by copper ion in the thiosulphate-ammonia solution. The direct possible product of thiosulphate decomposition is tetrathionate, which may be oxidized to sulphite. Sulphate is supposed to be the final product of these oxidation reactions. Both tetrathionate and sulphite may be reversed to thiosulphate if the solution is oxygen deficient. Zinc metal is able to convert tetrathionate to thiosulphate as well. Another possible way of generating thiosulphate is through the oxidation of sulphide anion dissolved from the sulphide minerals. Some major reactions in this multilevel decomposition procedure will be discussed in Section 6.2.

It was demonstrated that the catalysis function of copper ion might disturb the stability of thiosulphate, sulphite and tetrathionate. Free copper ion, copper thiosulphate complexes and copper ammonia complexes are the major compounds of copper in gold leaching solution. Copper ammonia complex is an essential catalyst for the gold dissolution. Under typical gold leaching conditions, cupric thiosulphate complex is not stable in ammonia solution and may be reduced to cuprous complex. Both cupric free ion and cupric ammonia complexes are the most possible constituents to oxidize and decompose thiosulphate.

Thus, to improve the stability of thiosulphate, the oxygen content and copper amount in solution should be as low as possible. Thus, theoretically, there are five possible ways to stabilize thiosulphate, these being to:

A. Maintain the oxygen supply at the lowest required level.

B. Maintain a high ammonia concentration, which may increase the stability of cupric amine complex. Minimize the concentration of thiosulphate to avoid the generation of cuprous thiosulphate complex.

$$Cu^{2+} + 4NH_3 \rightarrow Cu(NH_3)_4{}^{2+} \qquad (6\text{-}1)$$

C. Add some chelating agents such as EDTA, to complex copper free ion and prevent the formation of copper thiosulphate complexes and mask the excess copper content.

$$Cu^{2+} + H_4X \rightarrow CuX^{2-} + 4H^+ \text{ (X=EDTA anion)} \qquad (6\text{-}2)$$

D. Reduce the concentration of copper in the leaching solution to a minimum required amount.

E. Replace copper ion with alternative metal catalysts, such as nickel ion.

6.1.1 An Introduction of the Multi-level Decomposition Chemistry of Thiosulphate

From the experimental results and evidence of this investigation (Chapters 4 and 5), the following reactions were suggested to explain the process of thiosulphate decomposition in gold leaching process. The primary product of thiosulphate oxidation is tetrathionate. Sulphite and sulphate are the secondary and the final oxidation products consequently. The presence of sulphide anion could reduce sulphite back to thiosulphate. In the zinc precipitation process, gold thiosulphate and cuprous thiosulphate complexes are deconstructed and generate free thiosulphate anions. Tetrathionate is also decomposed to thiosulphate and sulphite in the addition of zinc. In the absence of copper after zinc precipitation, thiosulphate may be decomposed to sulphite directly and rapidly. The final stable product is still sulphate at this stage. Due to their insignificance in this system, some intermediate products, such as: $S_5O_6^{2-}$ etc., are not studied in the following section.

(1) The First Step of Thiosulphate Oxidation

The driving force of this oxidation reaction is dissolved oxygen. Both copper free ion and copper ammonia complexes catalysed the oxidation. Thiosulphate may oxidize the cupric ions and cupric ammonia complexes and decompose to tetrathionate by a series of catalysis reactions.

Overall reaction:

$$4S_2O_3^{2-} + O_2 + 2H_2O \xrightarrow{Cu^{2+}\text{ as catalyst}} 2S_4O_6^{2-} + 4OH^- \qquad (6\text{-}3)$$

Catalysis Reactions:

$$2S_2O_3^{2-} + 2Cu(NH_3)_4^{2+} \rightarrow 2Cu^+ + S_4O_6^{2-} + 8NH_3 \qquad (6\text{-}4)$$

$$2S_2O_3^{2-} + 2Cu^+ \rightarrow Cu_2(S_2O_3)_2^{2-} \qquad (6\text{-}5)$$

$$2S_2O_3^{2-} + Cu_2(S_2O_3)_2^{2-} \rightarrow 2Cu(S_2O_3)_2^{3-} \qquad (6\text{-}6)$$

$$2Cu(S_2O_3)_2^{3-} + 8NH_3 + 0.5O_2 + H_2O \rightarrow 2Cu(NH_3)_4^{2+} + 4S_2O_3^{2-} + 2OH^- \qquad (6\text{-}7)$$

Equations 6-4 to 6-7 indicate that thiosulphate is not oxidized directly by oxygen. Cupric ion and its complexes are acting as the oxidation catalyst in the presence of ammonia. After the generation of tetrathionate, all the consumed copper and ammonia are recovered. Tetrathionate is meta-sable in the presence of copper and ammonia.

Because there is no universal conclusion about the form of cuprous thiosulphate complex in typical leaching solution, I use $Cu(S_2O_3)_2^{3-}$ to write the equations in this investigations. However, $Cu(S_2O_3)_2^{3-}$ in the Equations 4-5 to 4-7 may be replaced by $Cu(S_2O_3)_3^{5-}$ when $Cu(S_2O_3)_3^{5-}$ is proved to be more stable.

(2) The Second Step of thiosulphate Oxidation

In the presence of oxygen, tetrathionate in copper-ammonia solution is oxidized to sulphite (see Equation 6-8).

$$S_4O_6^{2-} + 1.5O_2 + 6OH^- \longrightarrow 4SO_3^{2-} + 3H_2O \qquad \textbf{(6-8)}$$

The oxidation of tetrathionate is a complicated process. The formation of sulphite is possible the result of tetrathionate decomposition as shown in Equation 6-9. The generated thiosulphate is oxidized to tetrathionate soon. Thus Equation 6-8 can describe the overall reaction.

$$2S_4O_6^{2-} + 6OH^- \longrightarrow 3S_2O_3^{2-} + 2SO_3^{2-} + 3H_2O \qquad \textbf{(6-9)}$$

(3) The Third Step of Thiosulphate Oxidation

Oxygen will further oxidize the sulphite into sulphate, which is supposed to be a stable final product in thiosulphate solution (see Equation 6-10). Cupric ion and its ammonia complexes act as catalysts for this oxidation. This catalysis function was described in

"Standard Method for the Examination of Water and Wastewater" (Clesceri et al., 1989). Thiosulphate may be oxidized to tetrathionate by sulphite in the absence of oxygen (see Equation 6-11).

Reactions:

$$4SO_3^{2-} + 3O_2 + 2H_2O \longrightarrow 4SO_4^{2-} + 4OH^- \qquad \textbf{(6-10)}$$

$$3S_2O_3^{2-} + 2SO_3^{2-} + 3H_2O \longrightarrow 2S_4O_6^{2-} + 6OH^- \qquad \textbf{(6-11)}$$

The oxidation of sulphite by oxygen is catalysed by cupric ion and cupric ammonia complexes with a similar mechanism described in Equations 6-5, 6-6 and 6-7. In the presence of ammonia, sulphite is oxidized to sulphate as shown in Equation 6-12. The consumed copper and ammonia are recovered after the oxidation of sulphite.

$$SO_3^{2-} + 2Cu(NH_3)_4^{2+} + H_2O \rightarrow SO_4^{2-} + 2Cu^+ + 2H^+ + 8NH_3 \qquad \textbf{(6-12)}$$

(4) Reduction of Tetrathionate to Thiosulphate

Tetrathionate is not stable and can be converted to thiosulphate when the copper concentration is extremely low (see Equation 6-13). When copper exists in solution, tetrathionate decomposes slowly to thiosulphate and sulphite. Trithionate can be produced in the presence of sulphite and tetrathionate in high concentration (see Equation 6-14).

Reaction:

$$2S_4O_6^{2-} + 6OH^- \leftrightarrow 3S_2O_3^{2-} + 2SO_3^{2-} + 3H_2O \qquad (6\text{-}13)$$

$$SO_3^{2-} + S_4O_6^{2-} \leftrightarrow S_3O_6^{2-} + S_2O_3^{2-} \qquad (6\text{-}14)$$

(5) Sulphide mineral dissolution by ammonia

As shown in Equation 6-15, metal sulphide minerals can be dissolved in a high concentration of ammonia. This is observed by the color changes of ammonia solution, i.e., the blue color of copper ammonia solution. Due to the dissolution of metal ions, the sulphite anion was dissolved in ammonia solution. The increase of ammonia concentration may accelerate the dissolution of copper sulphide minerals. The presence of thiosulphate might also dissolve metal sulphide minerals. The dissolved sulphide anion is unstable at pH lower than 13.

$$MeS + xNH_3 \rightarrow [Me(NH_3)_x]^{2+} + S^{2-} \qquad (6\text{-}15)$$

(6) Sulphite reduction by sulphide ion

Sulphite may be reduced to thiosulphate by free sulphide ion (see Equation 6-16). This reaction is not active when the oxygen content and solution acidity are high, because sulphide may react with oxygen and produce sulphate.

$$4SO_3^{2-} + 6H^+ + 2S^{2-} \rightarrow 3S_2O_3^{2-} + 3H_2O \qquad (6\text{-}16)$$

(7) Tetrathionate Decomposition by Zinc Precipitation

Zinc powder can decompose tetrathionate very fast and result in thiosulphate and sulphite. Copper in solution is replaced by zinc and is precipitated on the surface of zinc particles. The ratio of thiosulphate and sulphite produced by tetrathionate depends on the oxygen supply in solution. High dissolved oxygen may reduce the generation of thiosulphate. Besides the decomposition of tetrathionate, zinc powder can also deconstruct cuprous thiosulphate complexes and gold thiosulphate complexes and generate free thiosulphate anion.

<u>Reaction:</u>

$$2S_4O_6^{2-} + 6OH^- \xrightarrow{\text{Zinc Powder}} 3S_2O_3^{2-} + 2SO_3^{2-} + 3H_2O \qquad (6\text{-}17)$$

$$Au(S_2O_3)_2^{3-} + 0.5Zn \longrightarrow Au + 2S_2O_3^{2-} + 0.5Zn^{2+} \qquad (6\text{-}18)$$

$$Cu(S_2O_3)_3^{5-} + 0.5Zn \longrightarrow Cu + 3S_2O_3^{2-} + 0.5Zn^{2+} \qquad (6\text{-}19)$$

(8) Thiosulphate direct decomposition after zinc precipitation

The thiosulphate is produced in solution after zinc precipitation. Due to the instability of tetrathionate in the absence of copper ion, thiosulphate may decompose again directly to sulphite and sulphate in the presence of oxygen.

<u>Reactions:</u>

$$S_2O_3^{2-} + O_2 + H_2O \longrightarrow 2SO_3^{2-} + 2H^+ \qquad (6\text{-}20)$$

$$SO_3^{2-} + 0.5O_2 \longrightarrow SO_4^{2-} \qquad (6\text{-}21)$$

6.2 The Effect of Variables and Additives

After the introduction of thiosulphate decomposition chemistry, a brief discussion will be carried out on the effects of variables and additives including the solution pH, sulphur composites additives, copper addition and its complexing agents, oxygen supply, mineral types, pulp density and zinc precipitation.

6.2.1 Solution pH

The gold corrosion reactions produce hydroxide anions during the process and a solution with pH higher then 10.5 will bring a negative effect on gold dissolution. The production of sulphide in solution at high pH may increase the metal sulphide precipitation. At the same time, solution pH should be higher than 9 to prevent the generation of elemental sulphur.

An Eh-pH diagram is one of the most important tools for theoretical researchers. Optimum solution pH should be carefully defined to control the location of the leaching condition. Because of the complexity of Eh-pH of this system, pH was controlled in the range of 9.2 to 10.5

6.2.2 Ammonia Concentration

Ammonia is a basic reagent for a gold leaching system. It not only catalyses the gold oxidation reaction but also prevents the thiosulphate decomposition by reducing the copper thiosulphate complexes. The complexing ability of ammonia with many metal ions can also help to extract copper from sulphide minerals and prevent the formation of copper sulphide film on the surfaces of gold particles. It also helps to reduce the requirement for additional copper catalyst. Due to the small solubility of ammonia ferrous and ferric complex, the iron minerals actually cannot be extracted into solution. Thus, iron impurities can be ignored in the system.

In the range of 0.3 M and 6 M ammonia, an increase of ammonia concentration generally has a positive effect on gold extraction and thiosulphate stability. This is because of the ammonia complexing ability with copper ion. The excessive ammonia may increase the solution pH and generate metal hydroxides.

6.2.3 Sulphur Compounds

The sulphur compounds include thiosulphate, tetrathionate, sulphite, sulphate and sulphide. Thiosulphate is the basic reagent for thiosulphate gold leaching. The concentration of thiosulphate directly affects the reagent consumption. Tetrathionate, sulphite and sulphate are the major decomposition products of thiosulphate. Sulphide is a by-product of the copper sulphide mineral dissolution by ammonia-thiosulphate solution. The addition of these species may consume dissolved oxygen, retard the decomposition of thiosulphate and introduce supplemental sulphur into the solution.

A. Sulphite

Sulphite salts and sulphur dioxide gas are the major types of sulphite additive in gold leaching practice. Sulphite is one of the most important additives being suggested in thiosulphate gold leaching. No consistent and pervasive result both in thiosulphate stability and gold extraction has been reported.

From the view point of thiosulphate decomposition chemistry, there are three major reasons for the application of sulphite. Sulphite in solution may react with dissolved sulphide anions, which are extracted from sulphide minerals. Even when there is no significant sulphide presence in the solution, sulphite, as a product of thiosulphate decomposition might also retard the thiosulphate decomposition reactions. As an active reductant, sulphite might improve the thiosulphate stability by consuming dissolved oxygen and reduce the driving force of thiosulphate oxidations.

However, with the presence of copper, sulphite becomes the secondary decomposition product of thiosulphate. The additional sulphite can only affect thiosulphate stability indirectly through the increase of tetrathionate concentration. Thus, the improvement might be insignificant. As the result of increased oxygen consumption by additional sulphite, the solution oxygen supply for gold extraction might be reduced. The lack of oxygen may lead to low gold extraction especially in closed-vessel gold leaching.

B. Sulphate

The sulphate additive was also being suggested to reduce thiosulphate decomposition. The roasting operation on sulphide gold ore could yield an alternative sulphate supply as well. No consistent and pervasive result has been reported about the effect of sulphate.

Sulphate is supposed to be the final product of thiosulphate decomposition. When the solution pH is high, almost all the thiosulphate will be decomposed to sulphate in the presence of oxygen. The additional sulphate should retard the oxidation reactions and improve the stability of the reductants.

However, the results of this investigation did not show significant improvement by sulphate additions. The weak effect of sulphate is an indication that there is no direct transformation from sulphate to thiosulphate. Sulphate affects the concentration of thiosulphate indirectly through the increase of sulphite and tetrathionate concentrations.

C. **Sulphide**

Sulphide is supplied by additional soluble sulphide salts or the dissolution of sulphide minerals. Sulphide is claimed to be a source of thiosulphate by the reaction with sulphite. At the same time, sulphide might consume excessive oxygen and stabilize thiosulphate. The study on mineral types in this investigation demonstrated that thiosulphate stability was increased significantly for the ore containing more sulphide minerals

The solution pH between 9.2 and 10.5 is not favourable for the stability of sulphide. The excessive sulphide addition might compete with gold in the usage of oxygen and promote the generation of metal sulphide films on the surface of ore particles. The additional of sulphide salts are not suggested as an effective addition to reduce thiosulphate consumption.

D. Thiosulphate

Thiosulphate is a major reagent in gold leaching systems and readily decomposes into various compounds. It was demonstrated in this investigation that higher thiosulphate concentration leads to a higher thiosulphate consumption.

Aylmore et al. (2001) plotted the Eh-pH diagrams of both high and low thiosulphate concentration systems and concluded that the enlargement of the copper amine area in the Eh-pH diagram required a high concentration system.

This investigation was conducted initially under high thiosulphate concentration conditions. It was believed that high thiosulphate concentrations might improve the formation of gold-thiosulphate complexes. However, the thiosulphate consumption was very high. The effect of low-thiosulphate gold leaching was studied. Results demonstrated the possibility of gold leaching in low thiosulphate solutions with longer duration time and lower thiosulphate consumption.

E. Tetrathionate

Tetrathionate is the major and primary oxidation product of thiosulphate in gold leaching solution. The structure of tetrathionate is shown in Figures 6-2.

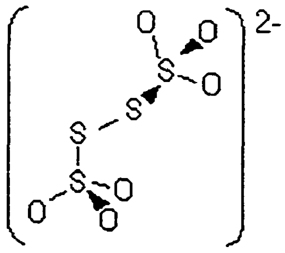

Figure 6-2 Structure of Tetrathionate Anion

As discussed in Section 6.1, the existence of tetrathionate depends on the presence of copper ions. In the absence of copper, tetrathionate might decompose to thiosulphate and sulphite rapidly. The addition of tetrathionate in thiosulphate solution may remarkably prevent thiosulphate form oxidation. However, due to the high price of this reagent, tetrathionate is not suggested as an economical additive.

6.2.4 Copper Species

The copper species affect both gold extraction reactions and thiosulphate decomposition reactions. Copper complexes are one of the sources of gold extraction catalyst. At the same time, it was observed that copper did reduce the thiosulphate stability. In the thiosulphate decomposition chemistry described in Section 6.1, it was concluded that copper ion and its ammonia complexes are the catalysts in the oxidation reactions of thiosulphate, tetrathionate and sulphite oxidations.

Copper exists in ammonia solution in many possible forms including copper ions (I or II), copper (I or II) amine complexes, copper (I or II) thiosulphate complex and possibly cupric tetrathionate complex. Copper complex stability constants are listed as below.

$Cu(NH_3)^{2+}$=10.86

$Cu(NH_3)_4^{2+}$=13.32

$Cu(S_2O_3)_3^{5+}$=13.71

There are three major electrochemical reactions for these copper species, including the reduction of cupric ion to cuprous ion, the reduction of cupric amine to cuprous amine and the reduction of cupric amine to cuprous thiosulphate complex. Obviously, the above redox reactions are accompanied by the complexing activities. As mentioned in the gold extraction chemistry, the redox reaction of cupric amine and cuprous amine complex is responsible for the catalysis of gold corrosion reactions. Beside the influences in the oxidation reactions, copper contents might affect the dissolution and precipitation of sulphide anion and indirectly affect the thiosulphate stability.

6.2.5 Chelating Agents (EDTA and NTA)

EDTA (Ethylenediaminetetra-acetic acid or diamino-ethanetetra-acetic acid) was studied for exploration of the thiosulphate decomposition chemistry and as a potential additive for better thiosulphate stability. NTA (Ammoniatriacetic Acid) is one of the most important complexions other than EDTA. The stability constants of NTA chelates with most metals are lower than of EDTA. NTA is used as a versatile and less expensive masking reagent for industry purposes. The structures of EDTA and NTA are shown in Figure 6-3 and 6-4.

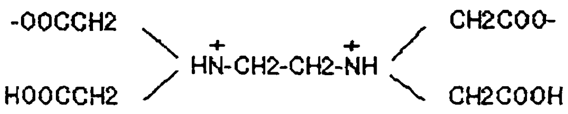

Figure 6-3 Structure of EDTA

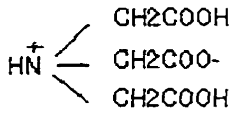

Figure 6-4 Structure of NTA

EDTA forms a complex with copper ion in a 1:1 ratio. The cuprous EDTA complex is possible but much less stable than cupric EDTA complex. Because of the EDTA complex, CU (II) / Cu (I) potential was moved to the lower end in the Eh-pH diagram.

The logarithmic stability constants of EDTA and NTA are shown in the following list. (West, 1969)

EDTA-Ca=10.7
EDTA-Co=16.21
EDTA-Cu(II)=18.79
EDTA-Fe(II)=14.33
EDTA-Fe(III)=25.1
EDTA-Ni=18.56
EDTA-Zn=16.26
EDTA-Ag=7.32
NTA-Ca=6.41
NTA-Co=10.61
NTA-Cu(II)=12.68
NTA-Ni=11.26
NTA-Zn=10.45

In a gold leaching system, EDTA complexes with free copper ion and reduces the Cupric/Cuprous potential to a very low level (West, 1969). The masking of copper ion helps to prevent the catalysis of thiosulphate decomposition. At the same time EDTA prevents the creation of metal sulphide films on the surfaces of ore particles. EDTA might also change the oxygen distribution in the leaching solution. The gold oxidation is promoted when the thiosulphate oxidation was retarded.

6.2.6 Supply of Oxygen as an Oxidant

Through the study of temperature, oxygen pressure, and copper catalysis, an important conclusion was made that both gold extraction and thiosulphate decomposition are oxidation reactions. The equilibrium potentials for $Cu(NH_3)_4^{2-}/Cu(S_2O_3)_3^{5-}$ and

$Cu(NH_3)_4^{2-}/Cu(S_2O_3)_2^{3-}$ are 0.22v and 0.14v respectively. The equilibrium potentials for $S_2O_3^{2-}/S_4O_6^{2-}$ and $Au/Au(NH_3)_2^{+}$ are about 0.12v and 0v respectively. So theoretically, $Cu(NH_3)_4^{2-}$ can readily oxidize $S_2O_3^{2-}$ and Au. The oxidation driving force for gold is higher than that for thiosulphate. That means thiosulphate is more stable than gold. The potential of leaching solution is decided by the strength of oxygen, reductants and other oxidants in solution. The increase of oxygen concentration will pull up the solution potential and increase the driving forces of both gold oxidation and thiosulphate oxidation.

Oxygen is supplied mainly from the air dissolved in the leaching solution. Open-vessel or closed-vessel are two major operational methods of oxygen supply. The changes of the air/oxygen pressure or the gas flow rate might also affect the oxygen supply strength.

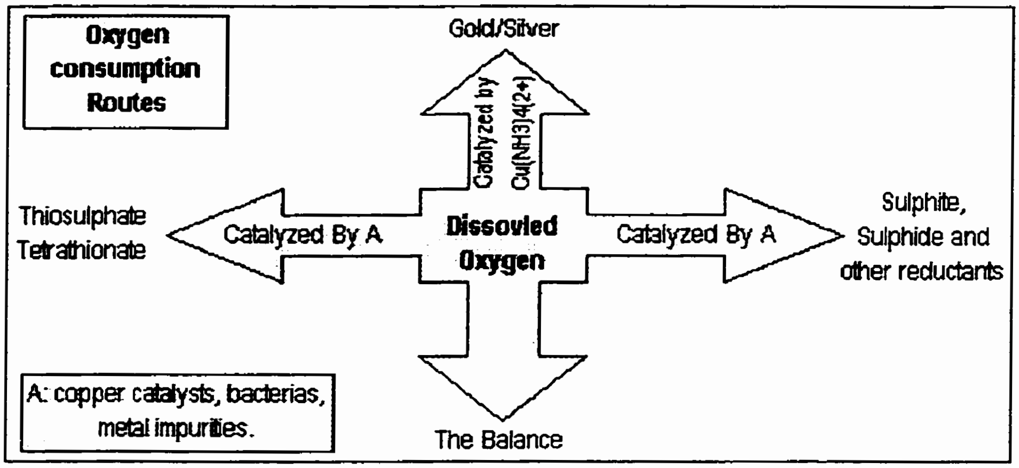

Figure 6-5 DO (Dissolved Oxygen) Distribution in Gold Leaching Solution

Figure 6-5 shows the possible oxygen consumption processes of thiosulphate lixiviant. Part of the dissolved oxygen is consumed in gold dissolution. Thiosulphate decomposition to tetrathionate, sulphite and sulphate also consumes oxygen. Thus, it is important for thiosulphate gold leaching to reduce or eliminate the thiosulphate decomposition.

6.2.7 Mineral Types

Gold extraction and thiosulphate stability are affected greatly by the contents of sulphide minerals, oxide minerals, and copper minerals, etc. The experimental results from this investigation indicate that more thiosulphate was consumption by the oxide ore. The increase of sulphide percentage in this ore reduced the thiosulphate consumption greatly. The roasting of the sulphide minerals to sulphate minerals decreased the thiosulphate consumption slightly.

A soluble sulphide mineral contributes a source of metal ion and sulphide anion in ammonia-thiosulphate solution. The dissolved sulphide anion might consume oxygen content and reduce the oxidation of thiosulphate in the solution. Copper minerals, especially the sulphide minerals, can be a source of copper catalyst. The dissolution of copper could be adjusted partly by the grinding time and the concentration of ammonia-thiosulphate.

6.2.8 Amino Acid

Didier Michel and Jean Frenay (1998) suggested amino acid as an additive for thiosulphate stability. Glycine (NH_2CH_2COOH) is the one of most common amino acids (see Figure 6-6). It is a kind of single amino with an organic acid radical and a characteristic radical. It was claimed that amino acid is a type of gold complexing agent, which forms a stable aurous complex. At the same time, the amino copper complex will replace ammonia copper complex to act as the catalyst for gold extraction. There was no experimental data presented.

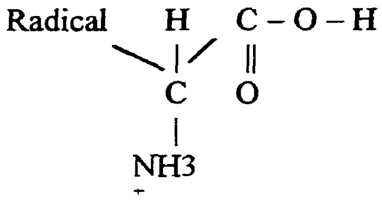

Figure 6-6 Structure of Glycine

The standard complexation potential of gold with glycine is 0.632 V. The glycine complexes with cuprous and cupric ions are 10.1 and 15.64. The stability of these complexes is much lower than that of cupric EDTA chelate.

In this investigation, no significant improvements on thiosulphate stability and gold extraction were observed by adding glycine in the leaching solution.

6.2.9 Pulp Density

Increasing pulp density in this investigation reduced thiosulphate consumption significantly. As the solution volume was fixed, the dissolved oxygen did not increase with the increase of pulp density in the closed-vessel test. So the increase of pulp density has a similar effect as reducing the oxygen supply to one unit amount of ore.

Again, a higher pulp density can lead to more dissolution of sulphide anion, which might consume excess DO and improve thiosulphate stability. On the contrary, there will be a diffusion problem at a pulp density higher than 70% solids. The decrease of oxygen supply per ton of ore is another problem of high pulp density gold leaching. The gold dissolution rate will be slower. Longer duration time is preferred in this case.

6.2.10 Zinc Precipitation

Zinc precipitation is a promising method for gold recovery in future industry operation. As mentioned in Section 6.1, copper ion and its thiosulphate complex are the requirement of the formation of tetrathionate. Zinc powder removed most copper ion from solution and make the tetrathionate degrade to thiosulphate and sulphite instantly.

The amount of zinc powder is a major factor in the zinc precipitation. Because the gold and copper metal will cover the active surface of zinc powder, the sufficient supply of zinc active surface is important to gold recovery and thiosulphate recovery. The residue copper in solution may promote the re-dissolution of the precipitated gold after the entire zinc active surface was covered. The residue of copper also decreases the thiosulphate regeneration.

The zinc precipitation time is another important factor. Enough duration time ensures that gold completes precipitation. A longer duration time may increase the thiosulphate decomposition. An optimum operation time should be decided in industry operation.

It was also demonstrated that the oxygen supply is not necessary for zinc precipitation. So, during zinc precipitation process, it is suggested to keep the oxygen supply as low as possible.

7. Conclusions and Future Work

The results from the current investigation could be concluded as follows.

7.1 Conclusions

1. Copper ion and its complexes were demonstrated to accelerate gold extraction and the oxidation of thiosulphate. For a copper-bearing sulphide gold ore, in the solution containing 0.03M of copper sulphate, 88% of gold extraction was reached with 27 kg/t of thiosulphate consumption. Copper concentration should be reduced to 0.0015M or lower to reduce the thiosulphate consumption to 17 kg/t and keep the gold extraction higher than 88%. For a non-copper high-grade gold ore (J ore), copper concentration should be reduced from 0.01M to 0.001-0.005M to decrease the thiosulphate consumption from 24 kg/t to 14 kg/t and keep the gold extraction at about 95%.

2. In closed-vessel gold leaching of a sulphide type of ore, EDTA was used to chelate and control the concentration of copper ion. When copper concentration was 0.03M, the addition of EDTA at 0.03M helped to reduce the thiosulphate consumption from 29 kg/t to 23 kg/t. About 30% of thiosulphate was saved with an increase of gold extraction from 80% to 88%. For a high-grade sulphide gold ore, the addition of 0.03M EDTA into a 0.03M copper sulphate solution reduced the thiosulphate consumption from 24 kg/t to 16 kg/t with a 2% increase in gold extraction. When the copper concentration was lower than 0.0015M, the improvement by adding 0.0015M of EDTA become insignificant in this copper-bearing sulphide gold ore.

3. By consuming sulphite additives, thiosulphate consumption was reduced. The addition of 0.2 M sulphite reduced the thiosulphate consumption from 29kg/t to 26kg/t. The gold extraction was not improved significantly. But when sulphite concentration was too high, gold extraction in closed-vessel tests might be influenced. The addition of sulphite at 0.3M on a high-grade gold ore reduced the thiosulphate consumption from 24 kg/t to 19 kg/t with a 30% decrease in gold extraction from 92% to 62% only.

4. For a copper-bearing low-grade gold ore, the addition of 0.2M sulphate kept the thiosulphate consumption at about 29 kg/t with an increase of gold extraction from 80% to 87%. For a high-grade sulphite gold ore, the addition of 0.3M sulphate did not improve thiosulphate stability and gold extraction.

5. Gold leaching at low reagent concentration (0.1M thiosulphate, 0.1 M ammonia, and 0.0005M copper sulphate) was conducted. 88% of gold extraction was reached after 48 hours. The gold dissolution was slower due to the low reagent concentration. The reagent consumption in 48 hours was 27 kg/t.

5. Gold leaching at high pulp density (6.15%) was studied under low reagent concentration conditions with 48 hours duration time. The changes of pulp density did not significantly affect the gold extraction (90%) and the thiosulphate consumption per litre of solution (30kg/t). The thiosulphate consumption per unit ton of ore was reduced obviously from 78 kg/t to 13 kg/t by increasing the pulp density from 29% to 62% of solid.

6. Mineral type is an important variable. The addition of sulphide minerals reduced thiosulphate consumption from 32 kg/t to 18 kg/t and decreased the gold

extraction from 88% to 76%. The additional oxide minerals consume more thiosulphate. The thiosulphate consumption was increased to 37 kg/t. The roasting of this sulphide gold ore reduced the thiosulphate consumption to 30 kg/t and increased the gold extraction by 3.3%.

7. Oxygen control by nitrogen gas flow led to an acceptable gold extraction (85%) in 8 hours. Thiosulphate consumption was reduced to 10 kg/t and lower when the nitrogen flow rate reached 5 ml/min or higher. When 40ml/min of nitrogen flow was applied, the gold extraction was reduced to 52%. Open-vessel gold leaching in tests with reagent maintenance had rapid gold dissolution and acceptable thiosulphate consumption. 78% of gold was extracted with 19 kg/t of thiosulphate consumption.

8. The thiosulphate decomposition chemistry model was established based on the observations of solution decomposition activities. Thiosulphate undergoes a multi-level decomposition. Tetrathionate is the primary product when copper exists in solution. Sulphite is the secondary product. Sulphate is the final product. Copper ion and its ammonia and thiosulphate complexes catalysed the above oxidation process.

9. The removal of copper ion by zinc precipitation altered the thiosulphate decomposition routes. Tetrathionate undergoes a rapid decomposition to thiosulphate and sulphite. The amount of regenerated thiosulphate depends on zinc powder addition amounts and zinc precipitation time. After the instant recovery of thiosulphate, thiosulphate solution may decompose fast to sulphite directly in the absence of dissolved copper.

7.2 Future Work

1. Low reagent strength gold leaching should be thoroughly studied to establish new optimum standard conditions (pH, thiosulphate, copper ions, ammonia, ammonium).

2. Effective additives should be selected and mixed to further improve overall performance. EDTA, NTA and sulphite (sulphur dioxide) are the most important additives. Cheaper substitutes for the above additives should be examined.

3. The optimum solution/pulp potential for a better thiosulphate stability and higher gold extraction should be explored. Oxygen control should be subjected to further study by both preliminary tests and electrochemistry methods. The optimum dissolved oxygen level should be found to maximize gold extraction and thiosulphate stability. A simple, economical and effective potential control method should be established for industry application.

4. The effect of ore compositions should be studied in more details. Pre-conditioning or pre-treatment should be studied as ways to improve the minerals properties. The costs and effects of these pre-treatment operations, including ammonia leaching, roasting, bio-oxidation, and high-pressure oxidation, should be compared for the purpose of industry application.

5. In the study of gold recovery methods (zinc precipitation, solvent extraction, resin, active carbon), the reduction of thiosulphate consumption should be systematically

studied. The recovery of thiosulphate and the feasibility of thiosulphate recycling should be studied.

6. High pulp densities should be applied in preliminary tests to explore their feasibility in industry application.

7. The chemistry model for thiosulphate decomposition/oxidation should be studied systematically by both experimental and theoretical methods.

8. The results and conclusions should be applied to gold leaching of various types of ore. A systematic laboratory method for determining the optimum conditions for various ore types should be established.

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VITA

Name: Chen Xia

Place and date of birth: China, 1972

Education: Candidate for M.Sc., September, 1998 ~ Present

Mining Engineering-Mineral Processing Option
Queen's University, Kingston, Ontario

B.Sc., September, 1990 ~ July, 1994

Metallurgy -Nonferrous Metallurgy Option Kunming Institute of Technology, Kunming, Yunnan, China

Experience: Research Assistant, September, 1998 ~ present,

Department of Mining Engineering, Queen's University, Kingston, Ontario, Canada

Metallurgical Engineer, December, 1996 ~ August, 1998

Beijing Xinhe Zhuye Plastic Steel Products Co., Beijing, China

Project Representative, August 1995 ~ December 1996

Metal and Steel Department, LG International Corp. (Beijing Office), Beijing, China

Appendix

Thiosulphate Solution Decomposition Tests

Effect Solution pH in close-vessel tests

Group No. **S-pH** *Experimenter:* **Chen Xia** *Date: Jan*. **2001**

Purposes

To study the effects of solution pH on thiosulphate stability

Procedure

A. Dissolve reagents in a 275ml bottle with ammonia solution
B. Adjust volume (50ml) and solution pH by water, sulfuric acid and sodium hydroxide
C. Seal the bottle and keep it rotating at 114 rmp
D. Refresh air at the 4th hour
E. Monitor the changes of thiosulphate

Reagent and Variables

Thiosulphate 0.3M, Ammonia 0.3M, Copper sulphate 0.01M

Test No.	S-pH-1	S-pH-2	S-pH-3	S-pH-4	S-pH-5
pH	9	9.5	9.9	10.2	10.5

Results — Thiosulphate Residue (M)

Time (h) \ No.	S-pH-1	S-pH-2	S-pH-3	S-pH-4	S-pH-5
0	0.300	0.300	0.300	0.300	0.300
4	0.271	0.230	0.231	0.236	0.243
24	0.189	0.177	0.193	0.193	0.202

Effect of sulphur compounds

Group No. S-S ***Experimenter:*** **Chen Xia** ***Date:*** **Aug. 2000**

Purposes

To compare the effects of various metal ions on thiosulphate stability

Procedure

A. Dissolve reagents in a 275ml bottle with ammonia solution
B. Adjust volume (50ml) and solution pH (10.2)
C. Seal the bottle and keep it rotating at 114 rmp
D. Refresh air at the 4th hour
E. Monitor the changes of thiosulphate and sulphite
F. Conduct Zn Precipitation at the 24th hour. (5min, 0.36g/50ml)

Reagent and Variables

Thiosulphate 0.3M, Ammonia 3M, Copper sulphate 0.03M

Test No.	Sulphite	Sulphate	Tetrathionate
S-S-1	0	0	0.075
S-S-2	0.3	0	0
S-S-3	0	0.3	0
S-S-4	0.3	0	0.075
S-S-5	0.3	0.3	0.075
S-S-6	0	0.3	0.075
S-S-7	0.3	0.3	0
S-S-8	0	0	0

Results — Thiosulphate Residue (M)

No. \ Time (h)	0	4	24	ZnPP
S-S-1	0.300	0.315	0.277	0.292
S-S-2	0.300	0.228	0.175	0.193
S-S-3	0.300	0.229	0.178	0.204
S-S-4	0.300	0.306	0.261	0.286
S-S-5	0.300	0.279	0.277	0.291
S-S-6	0.300	0.315	0.279	0.301
S-S-7	0.300	0.235	0.192	0.202
S-S-8	0.300	0.220	0.166	0.187

Results — Sulphite Residue (M)

No. \ Time (h)	0	4	24	ZnPP
S-S-1	0.000	0.004	0.000	0.005
S-S-2	0.300	0.190	0.119	0.138
S-S-3	0.000	0.004	0.007	0.004
S-S-4	0.300	0.120	0.043	0.075
S-S-5	0.300	0.145	0.064	0.087
S-S-6	0.000	0.004	0.001	0.005
S-S-7	0.300	0.202	0.130	0.163
S-S-8	0.000	0.004	0.003	0.011

Thiosulphate Solution Decomposition Tests

Effect of Air Supply Methods

Group No. **S-Air** ***Experimenter:*** **Chen Xia** ***Date:*** **Aug. 2000**

Purposes

To compare the effects of various air supply method on thiosulphate stability

Procedure

A. Dissolve reagents in a 2520ml bottle with ammonia solution
B. Adjust volume (250ml) and solution pH (10.2)
C. Set the bottle and keep it rotating at 59.5 rmp
D. Refresh air at the 4th hour, remove 50ml solution for zinc precipitation
E. Monitor the changes of thiosulphate and sulphite
F. Conduct Zn Precipitation at the 24th hour. (5min, 0.36g/50ml)

Reagent and Variables

Thiosulphate 0.3M, Ammonia 3M, Copper sulphate 0.03M

Test No.	S-Air-1	S-Air-2
Air supply	Open-vessel	Close-Vessel

Results — Thiosulphate Residue (M)

Time (h) \ No.	S-Air-1	S-Air-2
0	0.300	0.300
4	0.183	0.213
24	0.003	0.130
ZnPP at 4h	0.211	0.231
Zn PP at 24h	0.018	0.165

Results — Sulphite Residue (M)

Time (h) \ No.	S-Air-1	S-Air-2
0	0.000	0.000
4	0.006	0.000
24	0.003	0.008
ZnPP at 4h	0.002	0.004
Zn PP at 24h	0.013	0.018

Metal Ions in Tetrathionate Solution

Group No. **S-MeTT** *Experimenter:* **Chen Xia** *Date:* **Aug. 2000**

Purposes

To compare the effects of various metal ions on the generation of thiosulphate and sulphite in tetrathionate solution

Procedure

A. Dissolve reagents in a 275ml bottle with ammonia solution
B. Adjust volume (50ml) and solution pH (10.2)
C. Seal the bottle and keep it rotating at 114 rmp
D. Refresh air at the 4th hour
E. Monitor the changes of thiosulphate and sulphite
F. Conduct Zn Precipitation at the 24th hour. (5min, 0.36g/50ml)

Reagent and Variables

Tetrathionate 0.3M, Ammonia 3M

Test No.	S-MeTT-1	S-MeTT-2	S-MeTT-3
Cu sulphate (M)	0.03	0	0
Ni Sulphate (M)	0	0	0.03
Co Chloride (M)	0	0.03	0

Results — Thiosulphate Residue (M)

Time (h) \ No.	S-MeTS-1	S-MeTS-2	S-MeTS-3
0	0.000	0.000	0.000
4	0.025	0.060	0.063
24	0.006	0.076	0.093
Zn PP	0.022	0.108	0.096

Results — Sulphite Residue (M)

Time (h) \ No.	S-MeTS-1	S-MeTS-2	S-MeTS-3
0	0.000	0.000	0.000
4	0.007	0.006	0.001
24	0.004	0.001	0.003
ZnPP	0.022	0.039	0.001

Metal Ions in Thiosulphate Solution

Group No. **S-MeTS** *Experimenter:* **Chen Xia** *Date:* **Aug. 2000**

Purposes

To compare the effects of various metal ions on thiosulphate stability

Procedure

A. Dissolve reagents in a 275ml bottle with ammonia solution
B. Adjust volume (50ml) and solution pH (10.2)
C. Seal the bottle and keep it rotating at 114 rmp
D. Refresh air at the 4th hour
E. Monitor the changes of thiosulphate and sulphite
F. Conduct Zn Precipitation at the 24th hour. (5min, 0.36g/50ml)

Reagent and Variables

Thiosulphate 0.3M, Ammonia 3M

Test No.	S-MeTS-1	S-MeTS-2	S-MeTS-3
Cu sulphate (M)	0.03	0	0
Ni Sulphate (M)	0	0.03	0
Co Chloride (M)	0	0	0.03

Results — Thiosulphate Residue (M)

Time (h) \ No.	S-MeTS-1	S-MeTS-2	S-MeTS-3
0	0.300	0.300	0.300
4	0.222	0.285	0.280
24	0.165	0.292	0.277
Zn PP	0.190	0.292	0.276

Results — Sulphite Residue (M)

Time (h) \ No.	S-MeTS-1	S-MeTS-2	S-MeTS-3
0	0.000	0.000	0.000
4	0.003	0.007	0.000
24	0.004	0.001	0.000
ZnPP	0.008	0.004	0.018

Thiosulphate Solution Decomposition Tests

Active Copper in Sulphite Solution

Group No. **S-CuSO3** ***Experimenter:*** **Chen Xia** ***Date:*** **Jul. 2000**

Purposes

To study the effects of active copper on the generation of thiosulphate in sulphite solution

Procedure

A. Dissolve reagents in a 275ml bottle with ammonia solution
B. Adjust volume (50ml) and solution pH (10.2)
C. Seal the bottle and keep it rotating at 114 rmp
D. Refresh air at the 4th hour
E. Monitor the changes of thiosulphate and sulphite
F. Conduct Zn Precipitation at the 24th hour. (5min, 0.36g/50ml)

Reagent and Variables

Sulphite 0.3M, Ammonia 3M

Test No.	S-CuSO3-1	S-CuSO3-2	S-CuSO3-3
Cu sulphate (M)	0.03	0.01	0.03
EDTA (M)	0	0	0.03

Results — Thiosulphate Residue (M)

Time (h) \ No.	S-CuSO3-1	S-CuSO3-2	S-CuSO3-3
0	0.000	0.000	0.000
4	0.001	0.001	0.001
24	0.003	0.003	0.003
Zn PP	0.003	0.003	0.003

Results — Sulphite Residue (M)

Time (h) \ No.	S-CuSO3-1	S-CuSO3-2	S-CuSO3-3
0	0.300	0.300	0.300
4	0.202	0.221	0.226
24	0.127	0.132	0.160
ZnPP	0.139	0.139	0.167

Active Copper in Tetrathionate Solution

Group No. **S-CuTT** ***Experimenter:*** **Chen Xia** ***Date:*** **Jul. 2000**

Purposes

To study the effects of active copper on the generation of thiosulphate and sulphite in tetrathionate solution

Procedure

A. Dissolve reagents in a 275ml bottle with ammonia solution
B. Adjust volume (50ml) and solution pH (10.2)
C. Seal the bottle and keep it rotating at 114 rmp
D. Refresh air at the 4th hour
E. Monitor the changes of thiosulphate and sulphite
F. Conduct Zn Precipitation at the 24th hour. (5min, 0.36g/50ml)

Reagent and Variables

Tetrathionate 0.075M, Ammonia 3M

Test No.	S-CuTT-1	S-CuTT-2	S-CuTT-3
Cu sulphate (M)	0.03	0.01	0.03
EDTA (M)	0	0	0.03

Results — Thiosulphate Residue (M)

Time (h) \ No.	S-CuTT-1	S-CuTT-2	S-CuTT-3
0	0.000	0.000	0.000
4	0.025	0.027	0.048
24	0.006	0.009	0.084
Zn PP	0.022	0.021	0.088

Results — Sulphite Residue (M)

Time (h) \ No.	S-CuTT-1	S-CuTT-2	S-CuTT-3
0	0.000	0.000	0.000
4	0.007	0.006	-0.001
24	0.004	0.006	0.001
ZnPP	0.022	0.015	0.005

Active Copper in Thiosulphate Solution

Group No. **S-CuTS** ***Experimenter:*** **Chen Xia** ***Date:*** **Jul. 2000**

Purposes

To study the effects of active copper on thiosulphate stability

Procedure

A. Dissolve reagents in a 275ml bottle with ammonia solution
B. Adjust volume (50ml) and solution pH (10.2)
C. Seal the bottle and keep it rotating at 114 rmp
D. Refresh air at the 4th hour
E. Monitor the changes of thiosulphate and sulphite
F. Conduct Zn Precipitation at the 24th hour. (5min, 0.36g/50ml)

Reagent and Variables

Thiosulphate 0.3M, Ammonia 3M

Test No.	S-CuTS-1	S-CuTS-2	S-CuTS-3
Cu sulphate (M)	0.03	0.01	0.03
EDTA (M)	0	0	0.03

Results — Thiosulphate Residue (M)

Time (h) \ No.	S-CuTS-1	S-CuTS-2	S-CuTS-3
0	0.300	0.300	0.300
4	0.222	0.243	0.294
24	0.165	0.207	0.282
ZnPP	0.190	0.222	0.285

Results — Sulphite Residue (M)

Time (h) \ No.	S-CuTS-1	S-CuTS-2	S-CuTS-3
0	0.000	0.000	0.000
4	0.003	0.004	0.000
24	0.004	0.000	0.001
ZnPP	0.008	0.000	0.003

Thiosulphate Regeneration By EDTA and Zinc Powder

***Group No.* EDTAZn** ***Experimenter:* Chen Xia** ***Date:* Aug. 2000**

Purposes

To compare the effects of EDTA and Zn powder on oxidized thiosulphate solution

Procedure

A. Divide oxidized thiosulphate solution into parts (50ml)
B. Add EDTA(0.06M) or Zn powder (0.6g/50ml) or their combination
C. Seal the jar and keep it rotating at 114 rmp
D. Monitor the changes of thiosulphate and sulphite

Reagent and Variables

Thiosulphate 0.3M, Ammonia 3M, Copper sulphate 0.03M

Test No.	Zn (g/50ml)	EDTA (M)
EDTAZn-1	0.6	0
EDTAZn-2	0	0.06
EDTAZn-3	0.6	0.06

Results — Thiosulphate Residue (M)

No. \ Time (min)	0	5
EDTAZn-1	0.245	0.265
EDTAZn-2	0.245	0.271
EDTAZn-3	0.245	0.283

Results — Sulphite Residue (M)

No. \ Time (min)	0	5
EDTAZn-1	0.000	0.010
EDTAZn-2	0.000	0.002
EDTAZn-3	0.000	0.002

Thiosulphate Solution Decomposition Tests

Effects of Amino Acid

Group No. **L-A** ***Experimenter:*** **Chen Xia** ***Date:*** **Aug. 1999**

Purposes

To study the effects of amino acid (glycine) on thiosulphate stability

Procedure

A. Connect bottles in a line by plastic tubes
B. Dissolve stable reagents in ammonia solution
C. Dissolve instable reagents in 50ml water
D. Mix solutions and adjust solution volume (500ml) and solution pH
E. Pump in a stable airflow saturated by ammonia
F. Start the test and keep monitoring the thiosulphate concentration

Operation conditions

Oxygen Supply	: Air Flow, 15ml/min
Solution pH	: 10.2
Duration time	: 36 hours

Reagent and Variables

Thiosulphate 0.1M, Ammonia 3M, Copper sulphate 0.03M

Test No.	L-A-1	L-A-2	L-A-3
Glycine (M)	0	0.03	0.05

Results — Thiosulphate Residue (M)

No.\Time (h)	0	10	24	36
L-A-1	0.100	0.052	0.022	0.015
L-A-2	0.100	0.051	0.034	0.017
L-A-3	0.100	0.052	0.030	0.020

Thiosulphate Solution Decomposition Tests

Effects of Sodium Sulphate

Group No. L-SO4 *Experimenter:* **Chen Xia** *Date:* **Jul. 1999**

Purposes

To study the effects of sulphate salt on thiosulphate stability

Procedure

A. Connect bottles in a line by plastic tubes
B. Dissolve stable reagents in ammonia solution
C. Dissolve instable reagents in 50ml water
D. Mix solutions and adjust solution volume (500ml) and solution pH
E. Pump in a stable airflow saturated by ammonia
F. Start the test and keep monitoring the thiosulphate concentration

Operation conditions

Oxygen Supply : Air Flow, 15ml/min
Solution pH : 10.2
Duration time : 36 hours

Reagent and Variables

Thiosulphate 0.5M, Ammonia 3M, Copper sulphate 0.03M

Test No.	L-SO4-1	L-SO4-2	L-SO4-3
Sulphate (M)	0	0.025	0.25

Results — Thiosulphate Residue (M)

No.\Time (h)	0	10	24	36
L-SO4-1	0.500	0.332	0.206	0.150
L-SO4-2	0.500	0.317	0.233	0.170
L-SO4-3	0.500	0.363	0.280	0.210

Effects of EDTA as an Additive

Group No. **L-EDTA** ***Experimenter:*** **Chen Xia** ***Date:*** **May 1999**

Purposes

To study the effects of EDTA as an additive

Procedure

A. Connect bottles in a line by plastic tubes
B. Dissolve stable reagents in ammonia solution
C. Dissolve instable reagents in 50ml water
D. Mix solutions and adjust solution volume (500ml) and solution pH
E. Pump in a stable airflow saturated by ammonia
F. Start the test and keep monitoring the thiosulphate concentration

Operation conditions

Oxygen Supply	: Air Flow, 15ml/min
Solution pH	: 10.2
Duration time	: 24 hours

Reagent and Variables

Thiosulphate 0.1M, Ammoina 3M, Copper sulphate 0.03M

Test No.	L-EDTA-1	L-EDTA-2	L-EDTA-3	L-EDTA-4
EDTA (M)	0	0.01	0.03	0.05

Results — Thiosulphate Residue (M)

No.\Time (h)	0	10	24	36
L-EDTA-1	0.100	0.050	0.022	0.016
L-EDTA-2	0.100	0.056	0.037	0.024
L-EDTA-3	0.100	0.080	0.069	0.065
L-EDTA-4	0.100	0.086	0.082	0.073

Effects of Copper Sulphate

Group No. **L-Cu** ***Experimenter:*** **Chen Xia** ***Date: May*** **1999**

Purposes

To study the effects of copper sulphate concentration on thiosulphate solution stability

Procedure

A. Connect bottles in a line by plastic tubes
B. Dissolve stable reagents in ammonia solution
C. Dissolve instable reagents in 50ml water
D. Mix solutions and adjust solution volume (500ml) and solution pH
E. Pump in a stable airflow saturated by ammonia
F. Start the test and keep monitoring the thiosulphate concentration

Operation conditions

Oxygen Supply	: Air Flow, 15ml/min
Solution pH	: 10.2
Duration time	: 48 hours

Reagent and Variables

Thiosulphate 0.5M, Ammonia 3M

Test No.	L-Cu-1	L-Cu-2	L-Cu-3	L-Cu-4
CUSO4 (M)	0.01	0.03	0.05	0.1

Results — Thiosulphate Residue (M)

No.\Time (h)	0	4	12	24	36	48
L-Cu-1	0.502	0.481	0.457	0.392	0.349	0.331
L-Cu-2	0.502	0.480	0.425	0.360	0.304	0.287
L-Cu-3	0.502	0.430	0.376	0.280	0.264	0.215
L-Cu-4	0.502	0.410	0.327	0.260	0.193	0.152

Effects of Ammonia Concentration

Group No. **L-NH3** ***Experimenter:*** **Chen Xia** ***Date:*** **Aug. 1999**

Purposes

To study the effects of ammonia concentration on thiosulphate solution stability

Procedure

A. Connect bottles in a line by plastic tubes
B. Dissolve stable reagents in ammonia solution
C. Dissolve instable reagents in 50ml water
D. Mix solutions and adjust solution volume (500ml) and solution pH
E. Pump in a stable airflow saturated by ammonia
F. Start the test and keep monitoring the thiosulphate concentration

Operation conditions

Oxygen Supply : Air Flow, 15ml/min
Solution pH : 11
Duration time : 24 hours

Reagent and Variables

Thiosulphate 0.1M, Copper sulphate 0.03M

Test No.	L-NH3-1	L-NH3-2	L-NH3-3
Ammonia (M)	1	3	5

Results — Thiosulphate Residue (M)

No.\Time (h)	0	10	24
L-NH3-1	0.100	0.033	0.013
L-NH3-2	0.100	0.045	0.020
L-NH3-3	0.100	0.049	0.021

Thiosulphate Solution Decomposition Tests

Effect of Solution pH

Group No. **L-pH** *Experimenter:* **Chen Xia** *Date: Jun.* **1999**

Purposes

To study the effect of solution pH on thiosulphate solution stability

Procedure

A. Connect bottles in a line by plastic tubes
B. Dissolve stable reagents in ammonia solution
C. Dissolve instable reagents in 50ml water
D. Mix solutions and adjust solution volume (500ml) and solution pH
E. Pump in a stable airflow saturated by ammonia
F. Start the test and keep monitoring the thiosulphate concentration

Operation conditions

Oxygen Supply : Air Flow 15ml/min
Duration time : 24 hours

Reagent and Variables

Thiosulphate 0.1M, Ammoina 3M, Copper sulphate 0.03M

Test No.	L-pH-1	L-pH-2	L-pH-3
pH	9.9	10.2	10.5

Results — Thiosulphate Residue (M)

No.\Time (h)	0	12	24
L-pH-1	0.100	0.032	0.013
L-pH-2	0.100	0.048	0.021
L-pH-3	0.100	0.052	0.023

Thiosulphate Solution Decomposition Tests

Effect of sulphite as an additive

Group No. **L-SO3** *Experimenter:* **Chen Xia** *Date: Jun.* **1999**

Purposes

To study the effect of sodium sulphite on thiosulphate solution stability

Procedure

A. Connect bottles in a line by plastic tubes
B. Dissolve stable reagents in ammonia solution
C. Dissolve instable reagents in 50ml water
D. Mix solutions and adjust solution volume (500ml) and solution pH
E. Pump in a stable airflow saturated by ammonia
F. Start the test and keep monitoring the thiosulphate concentration

Operation conditions

Oxygen Supply : Air Flow 15ml/min
Solution pH : 10.2
Duration time : 24 hours

Reagent and Variables

Thiosulphate 0.1M, Ammoina 3M, Copper sulphate 0.03M

Test No.	L-SO3-1	L-SO3-2	L-SO3-3	L-SO3-4	L-SO3-5
Sulphite (M)	0.005	0.01	0.02	0.03	0.05

Results — Thiosulphate Residue (M)

No.\Time (h)	0	12	24
L-SO3-1	0.100	0.032	0.015
L-SO3-2	0.100	0.034	0.014
L-SO3-3	0.100	0.047	0.021
L-SO3-4	0.100	0.043	0.017
L-SO3-5	0.100	0.041	0.022

Results — Sulphite Residue (M)

No.\Time (h)	0	12	24
L-SO3-1	0.005	0.003	0.001
L-SO3-2	0.010	0.004	0.001
L-SO3-3	0.020	0.012	0.001
L-SO3-4	0.030	0.009	0.003
L-SO3-5	0.050	0.017	0.006

Effect of Thiosulphate Initial Concentraiton

Group No. **L-TS** *Experimenter:* **Chen Xia** *Date: Jun.* **1999**

Purposes

To study the effect of thiosulphate initial concentration on thiosulphate solution stability

Procedure

A. Connect bottles in a line by plastic tubes
B. Dissolve stable reagents in ammonia solution
C Dissolve instable reagents in 50ml water
D. Mix solutions and adjust solution volume (500ml) and solution pH
E. Pump in a stable airflow saturated by ammonia
F Start the test and keep monitoring the thiosulphate concentration

Operation conditions

Oxygen Supply	: Air Flow 16.8ml/min
Solution pH	: 10.2
Duration time	: 24 hours

Reagent and Variables

Ammoina 3M, Copper sulphate 0.03M

Test No.	Thiosulphate
	M
L-TH-1	0.1
L-TH-2	0.3
L-TH-3	0.5

Results — Thiosulphate Residue (M)

No.\Time (h)	0	12	24
L-TH-1	0.100	0.033	0.018
L-TH-2	0.300	0.178	0.140
L-TH-3	0.500	0.347	0.280

Thiosulphate Solution Decomposition Tests

Effects of Various Additives

Group No. **L-Com** ***Experimenter:*** **Chen Xia** ***Date:*** **Aug-1999**

Purposes

To study the effects of various additives

Procedure

A. Connect bottles in a line by plastic tubes
B. Dissolve stable reagents in ammonia solution
C. Dissolve instable reagents in 50ml water
D. Mix solutions and adjust solution volume (500ml) and solution pH
E. Pump in a stable airflow saturated by ammonia
F. Start the test and keep monitoring the thiosulphate concentration

Operation conditions

Oxygen Supply : Air Flow, 15ml/min
Solution pH : 10.2
Duration time : 31 hours

Reagent and Variables

Thiosulphate 0.1M, Ammoina 3M, Copper sulphate 0.03M

Test No.	Sulphate	Sulphite	Sulphide	Sulphur Dioxide	EDTA
	M	*M*	*M*	*M*	*M*
L-Com-1	0	0	0	0.05	0
L-Com-2	0	0.05	0	0	0
L-Com-3	0	0	0.05	0	0
L-Com-4	0.05	0	0	0	0
L-Com-5	0	0	0	0	0.05

Results — Thiosulphate Residue (M)

No.\Time (h)	0	5	19	31
L-Com-1	0.100	0.056	0.020	0.014
L-Com-2	0.100	0.054	0.022	0.013
L-Com-3	0.100	0.062	0.017	0.008
L-Com-4	0.100	0.057	0.026	0.019
L-Com-5	0.100	0.087	0.072	0.067

Thiosulphate Solution Decomposition Tests

Effect of Airflow

Group No. **L-Com** *Experimenter:* **Chen Xia** *Date:* **May 1999**

Purposes

To study the effect of airflow on thiosulphate solution stability

Procedure

A. Connect bottles in a line by plastic tubes
B. Dissolve stable reagents in ammonia solution
C. Dissolve instable reagents in 50ml water
D. Mix solutions and adjust solution volume (500ml) and solution pH
E. Pump in a stable airflow saturated by ammonia
F. Start the test and keep monitoring the thiosulphate concentration

Operation conditions

Solution pH : 10.2
Duration time : 36 hours

Reagent and Variables

Thiosulphate 0.1M, Ammoina 3M, Copper sulphate 0.03M

Test No.	L-Air-1	L-Air-2	L-Air-3
Air (ml/Min)	0	8	15

Results — Thiosulphate Residue (M)

No.\Time (h)	0	10	24	36
L-Air-1	0.100	0.094	0.084	0.079
L-Air-2	0.100	0.075	0.040	0.025
L-Air-3	0.100	0.050	0.020	0.016

Gold leaching tests

Effects of Ammonium Thiosulphate Initial Concentration

Group No. : **E-TS** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Nov. 1999**

Purpose : To study the effect thiosulphate concentration on gold leaching performance

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 4th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Ammonia 0.3M, Copper sulphate 0.03M

Test No.	Thiosulphate (M)
E-TS-1	0.15
E-TS-2	0.2
E-TS-3	0.25
E-TS-4	0.3
E-TS-5	0.45

Results — Thiosulphate (M)

No.\ Time	0h	4h	24h	Cons. (kg/t)
E-TS-1	0.15	0.07	0.042	20.1636
E-TS-2	0.2	0.113	0.081	22.2173
E-TS-3	0.250	0.150	0.114	25.3912
E-TS-4	0.300	0.195	0.146	28.7518
E-TS-5	0.450	0.335	0.279	31.9257

Results — Metallurgical Balance

E-TS-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.92	0.48	81.40
Solid Residue	200	0.55	0.11	18.60
Calc. Head		2.95	0.59	100.00

E-TS-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.93	0.48	80.09
Solid Residue	200	0.60	0.12	19.91
Calc. Head		3.01	0.60	100.00

E-TS-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.04	0.51	82.10
Solid Residue	200	0.56	0.11	17.90
Calc. Head		3.11	0.62	100.00

E-TS-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.00	0.50	83.20
Solid Residue	200	0.50	0.10	16.80
Calc. Head		3.01	0.60	100.00

E-TS-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.02	0.51	84.71
Solid Residue	200	0.46	0.09	15.29
Calc. Head		2.99	0.60	100.00

Gold Leaching with De-Oxygen Operations

Group No. : **E-NoCu** **Experimenter : Chen** **Ore : Hope Brooke** **Jul. 2000**

Purpose : To study the possibility of low-oxygen gold leaching

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into beakers
B. Add 3M ammonia solution in beakers, pump in Nitrogen gas flow
C. Stir while deoxygen until the oxygen level is stable
D. Dissolve stable reagents in pulp
E. Add instable reagents, adjust solution volume and pH
F. Stirring the pulp for 8 hours, keep the flow rate of nitrogen gas
G. Monitor the concentration of thiosulphate
H. Conduct zinc precipitation process if required
I. Filter the pulp after 24 hours and collect samples for assays
J. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air (Nitrogen)
Grind	(-10 mesh sample) in a laboratory rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M, Ammonia 0.3M, Copper Sulphate 0.03M

Test No.	N2 Flow Rate (ml/min
E-N2-1	5
E-N2-2	10
E-N2-3	40

Results — Thiosulphate (M)

No.\ Time	0h	4h	8h	ZnPP	Cons. (kg/t)	Cons. After ZnPP(kg/t)
E-N2-1	0.300	0.235	0.244	0.272	10.4	5.2
E-N2-2	0.300	0.238	0.250	0.277	9.3	4.3
E-N2-3	0.300	0.242	0.255	0.278	8.4	4.1

Results — Metallurgical Balance

E-N2-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.32	0.33	51.99
Solid Residue	200	1.53	0.31	48.01
Calc. Head		3.18	0.64	100.00

E-N2-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.09	0.52	85.23
Solid Residue	200	0.45	0.09	14.77
Calc. Head		3.07	0.61	100.00

E-N2-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.08	0.52	86.38
Solid Residue	200	0.41	0.08	13.62
Calc. Head		3.01	0.60	100.00

Effects of Nickel Sulphate on Gold Leaching

Group No. : **E-Ni** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Oct. 2000**

Purpose : To study the effect Ni sulphate on gold leaching

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 4th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M, Ammonia 0.3M

Test No.	Ammonia (M)	Ni Sulphate (M)
E-Ni-1	3	0.001
E-Ni-2	3	0.005
E-Ni-3	3	0.01
E-Ni-4	1	0.005
E-Ni-5	0.3	0.005

Results — Thiosulphate (M)

No.\ Time	0h	4h	24h	Cons. (kg/t)
E-Ni-1	0.300	0.271	0.208	17.207
E-Ni-2	0.300	0.272	0.207	17.434
E-Ni-3	0.300	0.259	0.203	18.113
E-Ni-4	0.300	0.254	0.188	21.056
E-Ni-5	0.300	0.275	0.189	20.830

Results — Metallurgical Balance

E-Ni-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.18	0.55	90.40
Solid Residue	200	0.29	0.06	9.60
Calc. Head		3.02	0.60	100.00

E-Ni-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.14	0.53	89.00
Solid Residue	200	0.33	0.07	11.00
Calc. Head		3.00	0.60	100.00

E-Ni-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.21	0.55	88.85
Solid Residue	200	0.35	0.07	11.15
Calc. Head		3.11	0.62	100.00

E-Ni-4	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.21	0.55	90.09
Solid Residue	200	0.30	0.06	9.91
Calc. Head		3.06	0.61	100.00

E-Ni-5	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.18	0.54	86.90
Solid Residue	200	0.41	0.08	13.10
Calc. Head		3.13	0.63	100.00

Gold Leaching Without Additional Copper

Group No. : **E-NoCu** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Aug. 2000**

Purpose : To study the possibility of Non-Copper gold leaching

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Add 3M ammonia solution in bottles
C. Keep the bottles rotating on rolls for certain period of time
D. Dissolve stable reagents in ammonia solutions, fill solutions in bottles
E. Add instable reagents, adjust solution volume and seal the bottles
F. Keep the bottles rotating on rolls for 24 hours
G. Refresh the air in bottles at the 4th hour
H. Monitor the concentration of thiosulphate
I. Conduct zinc precipitation process if required
J. Filter the pulp after 24 hours and collect samples for assays
K. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratory rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M, Ammonia 0.3M

Test No.	Ore type	EDTA (M)
E-NoCu-1	Hope Brooke	0
E-NoCu-2	M	0
E-NoCu-3	Hope Brooke	0.0054

Results — Thiosulphate (M)

No.\ Time	0h	4h	24h	Cons. (kg/t)
E-NoCu-1	0.300	0.256	0.210	16.754
E-NoCu-2	0.300	0.260	0.237	11.773
E-NoCu-3	0.300	0.265	0.203	18.113

Results — Metallurgical Balance

E-NoCu-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.65	0.41	66.67
Solid Residue	200	1.03	0.21	33.33
Calc. Head		3.10	0.62	100.00

E-NoCu-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	4.11	1.03	61.92
Solid Residue	200	3.16	0.63	38.08
Calc. Head		8.29	1.66	100.00

E-NoCu-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.92	0.48	76.05
Solid Residue	200	0.76	0.15	23.95
Calc. Head		3.16	0.63	100.00

Effects of Low Copper Concentration on Gold Leaching

Group No. : **E-CuH** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Oct. 2000**

Purpose : To study the gold leaching under low copper concentration conditions.

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 4th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M, Ammonia 0.3M

Test No.	Copper sulphate (M)	EDTA (M)
E-CuH-1	0.0015	0
E-CuH-2	0.0015	0.0015
E-CuH-3	0.00075	0
E-CuH-4	0.00075	0.00075
E-CuH-5	0.03	0
E-CuH-6	0.03	0.03

Results — Thiosulphate (M)

No.\ Time	0h	4h	24h	After ZnPP	Cons. (kg/t)
E-CuH-1	0.300	0.261	0.209	0.220	16.97
E-CuH-2	0.300	0.265	0.210	0.218	16.80
E-CuH-3	0.300	0.266	0.209	0.215	16.97
E-CuH-4	0.300	0.259	0.208	0.213	17.26
E-CuH-5	0.300	0.209	0.157	0.186	26.70
E-CuH-6	0.300	0.240	0.188	0.204	21.04

Results — Metallurgical Balance

E-CuH-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.23	0.56	88.08
Solid Residue	200	0.38	0.08	11.92
Calc. Head		3.16	0.63	100.00

E-CuH-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.23	0.56	89.24
Solid Residue	200	0.34	0.07	10.76
Calc. Head		3.13	0.63	100.00

E-CuH-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.24	0.56	88.50
Solid Residue	200	0.36	0.07	11.50
Calc. Head		3.16	0.63	100.00

E-CuH-4	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.32	0.58	90.30
Solid Residue	200	0.31	0.06	9.70
Calc. Head		3.21	0.64	100.00

E-CuH-5	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.19	0.55	87.87
Solid Residue	200	0.38	0.08	12.13
Calc. Head		3.11	0.62	100.00

E-CuH-6	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.22	0.56	89.35
Solid Residue	200	0.33	0.07	10.65
Calc. Head		3.11	0.62	100.00

Effects of Mineral Properties on Gold Leaching

Group No. : **E-Ore** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Sep. 2000**

Purpose : To study the effect ore properties on gold leaching

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 4th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Pulp Density	44%
pH	10.2
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M, Ammonia 0.3M, Copper sulphate 0.03M

Test No.	Ore Sample (g)	FeO (g)	Roasting	CuFeS (g)
E-Ore-1	200	0	No	0
E-Ore-2	160	40	No	0
E-Ore-3	200	0	Yes	0
E-Ore-4	160	0	No	40

Roasting: 60min at 1200F in a furnace, stir every 15min

Results — Thiosulphate (M)

No.\ Time	0h	4h	24h	ZnPP	Cons. (kg/t)
E-Ore-1	0.300	0.183	0.127	0.156	32.4
E-Ore-2	0.300	0.166	0.105	0.147	36.5
E-Ore-3	0.300	0.187	0.139	0.163	30.2
E-Ore-4	0.300	0.206	0.206	0.225	17.6

Results — Metallurgical Balance

E-Ore-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.15	0.54	87.70
Solid Residue	200	0.38	0.08	12.30
Calc. Head		3.06	0.61	100.00

E-Ore-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.51	0.38	75.69
Solid Residue	200	0.61	0.12	24.31
Calc. Head		2.50	0.50	100.00

E-Ore-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.19	0.55	91.03
Solid Residue	200	0.27	0.05	8.97
Calc. Head		3.01	0.60	100.00

E-Ore-4	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.54	0.39	78.02
Solid Residue	200	0.54	0.11	21.98
Calc. Head		2.47	0.49	100.00

Gold Leaching with Low Reagent Strength and High Pulp-density

Group No. : **E-Pulp** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Nov. 2000**

Purpose : To study the possibility of low reagent strength gold leaching in high pulp density

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 48 hours
E. Refresh the air in bottls at the 8th, 24th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

pH	9.9
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Copper Sulphate 0.0005M

Test No.	Pulp-density %	Ammonia(M)	Thiosulphate (M)
E-Pulp-1	61.5	0.1	0.15
E-Pulp-2	61.5	0.3	0.3
E-Pulp-3	54.5	0.3	0.3
E-Pulp-4	44.4	0.3	0.3
E-Pulp-5	28.6	0.3	0.3

Results — Thiosulphate Consumption (Kg/t)

No.\ Time	0h	8h	24h	48h
E-Pulp-1	0.0	4.5	8.7	13.1
E-Pulp-2	0.0	6.3	12.3	17.4
E-Pulp-3	0.0	8.8	17.0	24.5
E-Pulp-4	0.0	13.4	26.6	37.5
E-Pulp-5	0.0	27.8	54.6	77.9

Results — Thiosulphate Consumption (Kg/L)

No.\ Time	0h	8h	24h	48h
E-Pulp-1	0.0	7.2	13.8	20.9
E-Pulp-2	0.0	10.1	19.6	27.8
E-Pulp-3	0.0	10.5	20.4	29.4
E-Pulp-4	0.0	10.7	21.2	30.0
E-Pulp-5	0.0	11.1	21.8	31.2

Results — Metallurgical Balance

Products\No.		E-Pulp-1	E-Pulp-2	E-Pulp-3	E-Pulp-4	E-Pulp-5
8h Sol.	S. Au(mg/L)	2.70	2.94	2.18	1.46	0.85
	Amount(ml)	250	250	250	250	250
	Ext. (%)	54.40	58.00	56.70	59.10	67.70
24h Sol.	S. Au(mg/L)	4.33	3.87	3.08	2.04	1.08
	Amount(ml)	250	250	250	250	250
	Ext.(%)	87.39	76.38	80.00	82.90	86.00
48h Sol.	S. Au(mg/L)	4.29	4.57	3.49	2.24	1.15
	Amount(ml)	250	250	250	250	250
	Ext. (%)	86.51	90.01	90.55	91.02	91.91
Residue	Grade(g/t)	0.42	0.32	0.30	0.28	0.25
	Amount(g)	400	400	300	200	100
Cal. Head	(g/t)	3.10	3.17	3.21	3.08	3.13

Low Reagent Strength Gold Leaching

Group No. : **E-Low** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Oct. 2000**

Purpose : To study the possibility of low reagent strength gold leaching

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 48 hours
E. Refresh the air in bottls at the 8th, 24th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	9.9
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.15M, Copper Sulphate 0.0005M

Test No.	Ammonia (M)
E-Low-1	0.1
E-Low-2	0.3

Results — Thiosulphate Consumption (Kg/t)

No.\ Time	0h	8h	24h	48h
E-Low-1	0.00	8.50	19.55	27.35
E-Low-2	0.00	9.00	18.80	26.35

Results — Metallurgical Balance

Products\No.		E-Low-1	E-Low-2
8h Sol.	S. Au(mg/L)	1.26	1.46
	Amount(ml)	250	250
	Ext. (%)	50.00	58.90
24h Sol.	S. Au(mg/L)	2.12	1.86
	Amount(ml)	250	250
	Ext.(%)	84.30	75.14
48h Sol.	S. Au(mg/L)	2.27	2.16
	Amount(ml)	250	250
	Ext. (%)	89.95	87.43
Residue	Grade(g/t)	0.32	0.39
	Amount(g)	200	200
Cal. Head	(g/t)	3.15	3.09

Gold leaching tests

Effects of Copper on Gold Leaching of J Ore

Group No. : **E-CuJ** **Experimenter : Chen Xia** **Ore : J ore** **Sep. 2000**

Purpose : To study the effect of active copper amount on gold leaching of J ore

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 4th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 60min/kg
Size	90% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M

Test No.	EDTA (M)	Copper Sulphate (M)	Ammonia (M)
E-CuJ-1	0	0.01	3
E-CuJ-2	0	0.003	3
E-CuJ-3	0	0.001	3
E-CuJ-4	0.01	0.01	3
E-CuJ-5	0	0.001	0.3

Results — Thiosulphate (M)

No.\ Time	0h	5h	24h	Cons. (kg/t)
E-CuJ-1	0.300	0.218	0.176	23.5
E-CuJ-2	0.300	0.235	0.202	19.2
E-CuJ-3	0.300	0.250	0.233	13.9
E-CuJ-4	0.300	0.216	0.172	25.5
E-CuJ-5	0.300	0.244	0.221	15.3

Results — Metallurgical Balance

E-CuJ-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	11.21	2.80	95.03
Solid Residue	200	0.73	0.15	4.97
Calc. Head		14.74	2.95	100.00

E-CuJ-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	11.37	2.84	95.36
Solid Residue	200	0.69	0.14	4.64

Calc. Head		14.90	2.98	100.00

E-CuJ-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	11.46	2.87	95.33
Solid Residue	200	0.70	0.14	4.67
Calc. Head		15.03	3.01	100.00

E-CuJ-4	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	11.31	2.83	96.30
Solid Residue	200	0.54	0.11	3.70
Calc. Head		14.68	2.94	100.00

E-CuJ-5	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	11.06	2.77	93.83
Solid Residue	200	0.91	0.18	6.17
Calc. Head		14.74	2.95	100.00

Gold leaching tests

A Study of Thiosulphate Regeneration in Zinc Precipitation Process

Group No. : **E-Zn1** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Jul. 2000**

Purpose : To observe the regeneration of thiosulphate in zinc precipitation process

Procedure :

A. Fill 50ml of pregnant solution in a 275ml glass jar
B. Add zinc powder and other reagents
C. Put sealed jars on rolls and keep them rotating constantly
D. Monitor the changes of thiosulphate and sulphite concentration
E. Assay the solutions for Zn/Cu contents

Reagent Conditions and Variables

Pregnant Solution 50ml, Thiosulphate 0.3M, Copper Sulphate 0.03M, Ammonia 3M, Zinc amoun 0.156, 0.3125, 0.4687, 0.625g/50ml, Precipitation time 5, 15, 30, 60min

Results — Metal Balance of gold leaching process

E-Zn1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	1250	2.08	2.60	83.33
Solid Residue	1000	0.52	0.52	16.67
Calc. Head		3.12	3.12	100.00

Results — Zn Precipitation

Zn=0.156g/50ml

Time(min)	TS(M)	Sulphite(M)	Au(mg/L)	Cu(mg/L)	Zn(mg/L)
0	0.204	0.0010	2.08	2100.00	0.00
5	0.241	0.0022	0.00	22.30	2105.00
15	0.236	0.0022	0.00	23.08	2125.00
30	0.226	0.0029	0.00	33.21	2690.00
60	0.216	0.0036	0.00	500.00	3380.00

Zn=0.3125g

Time(min)	TS(M)	Sulphite(M)	Au(mg/L)	Cu(mg/L)	Zn(mg/L)
0	0.204	0.0010	2.08	2100.00	0.00
5	0.229	0.0080	0.00	1.90	2110.00
15	0.229	0.0073	0.00	3.08	2160.00
30	0.228	0.0123	0.00	3.59	3530.00
60	0.225	0.0203	0.00	1.87	4915.00

Zn=0.4687g

Time(min)	TS(M)	Sulphite(M)	Au(mg/L)	Cu(mg/L)	Zn(mg/L)
0	0.204	0.0010	2.08	2100.00	0.00
5	0.229	0.0087	0.00	2.71	2330.00
15	0.228	0.0094	0.03	1.78	2965.00
30	0.223	0.0189	0.06	2.20	4225.00
60	0.216	0.0283	0.00	2.44	5990.00

Zn=0.625g

Time(min)	TS(M)	Sulphite(M)	Au(mg/L)	Cu(mg/L)	Zn(mg/L)
0	0.204	0.0010	2.08	2100.00	0.00
5	0.229	0.0123	0.00	1.21	2250.00
15	0.228	0.0160	0.04	2.26	2825.00
30	0.223	0.0210	0.00	1.33	4790.00
60	0.212	0.0305	0.00	4.95	7285.00

Effects of Additives on M Ore

Group No. : **E-Mcom** **Experimenter : Chen Xia** **Ore : M ore** **Jan. 2000**

Purpose : To study the effect of EDTA, sulphate and sulphite. An alternative ore type was used.

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 4th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 30min/kg
Size	90% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M, Ammonia 3M, Copper sulphate 0.03M

Test No.	EDTA (M)	Sulphite (M)	Sulphate (M)
E-Mcom-1	0	0	0
E-Mcom-2	0.03	0	0
E-Mcom-3	0	0.3	0
E-Mcom-4	0	0	0.3

Results — Thiosulphate (M)

No.\ Time	0h	5h	24h	Cons. (kg/t)
E-Mcom-1	0.300	0.214	0.172	23.9
E-Mcom-2	0.300	0.254	0.212	16.4
E-Mcom-3	0.300	0.264	0.200	18.6
E-Mcom-4	0.300	0.220	0.164	25.5

Results — Metallurgical Balance

E-Mcom-1	Amount mL, g	Assay, Au mg/L, g/t	Au Unit mg	Au Dis. %
Preg. solution	250	18.25	4.56	91.70
Solid Residue	200	2.06	0.41	8.30
Calc. Head		24.87	4.97	100.00

E-Mcom-2	Amount mL, g	Assay, Au mg/L, g/t	Au Unit mg	Au Dis. %
Preg. solution	250	18.22	4.55	93.92
Solid Residue	200	1.47	0.29	6.08
Calc. Head		24.24	4.85	100.00

E-Mcom-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	11.66	2.91	61.55
Solid Residue	200	9.10	1.82	38.45
Calc. Head		23.67	4.73	100.00

E-Mcom-4	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	18.03	4.51	89.42
Solid Residue	200	2.67	0.53	10.58
Calc. Head		25.21	5.04	100.00

Effects of Sodium Sulphate on Gold Leaching

Group No. : **E-SO4** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Nov. 1999**

Purpose : To study the effect sulphate concentration on gold leaching performance

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 4th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M, Ammonia 0.3M, Copper sulphate 0.03M

Test No.	Sodium Sulphate (M)
E-SO4-1	0
E-SO4-2	0.1
E-SO4-3	0.2

Results — Thiosulphate (M)

No.\ Time	0h	5h	24h	Cons. (kg/t)
E-SO4-1	0.243	0.170	0.122	29.1
E-SO4-2	0.250	0.181	0.126	27.7
E-SO4-3	0.250	0.179	0.128	27.4

Results — Metallurgical Balance

E-SO4-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.77	0.44	79.59
Solid Residue	200	0.57	0.11	20.41
Calc. Head		2.78	0.56	100.00

E-SO4-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.14	0.54	89.02
Solid Residue	200	0.33	0.07	10.98
Calc. Head		3.01	0.60	100.00

E-SO4-3	Amount mL, g	Assay, Au mg/L, g/t	Au Unit mg	Au Dis. %
Preg. solution	250	2.10	0.52	87.73
Solid Residue	200	0.37	0.07	12.27
Calc. Head		2.99	0.60	100.00

Effects of Sodium Sulphite on Gold Leaching

Group No. : **E-SO3** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Nov. 1999**

Purpose : To study the effect sulphite concentration on gold leaching performance

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 4th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M, Ammonia 0.3M, Copper sulphate 0.03M

Test No.	Sodium Sulphite (M)
E-SO3-1	0
E-SO3-2	0.1
E-SO3-3	0.2

Results — Thiosulphate (M)

No.\ Time	0h	5h	24h	Cons. (kg/t)
E-SO3-1	0.243	0.170	0.122	29.1
E-SO3-2	0.250	0.179	0.109	31.6
E-SO3-3	0.250	0.194	0.135	25.7

Results — Metallurgical Balance

E-SO3-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.77	0.44	79.59
Solid Residue	200	0.57	0.11	20.41
Calc. Head		2.78	0.56	100.00

E-SO3-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.98	0.50	87.82
Solid Residue	200	0.34	0.07	12.18
Calc. Head		2.82	0.56	100.00

E-SO3-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.82	0.46	81.34
Solid Residue	200	0.52	0.10	18.66
Calc. Head		2.80	0.56	100.00

Effects of Air Supply Methods on Gold Leaching

Group No. : **E-Air** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Nov. 1999**

Purpose : To study the effect open-vessel and close-vessel operation methods on gold leaching performance

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume, seal the bottles if required
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 4th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air in a capped bottle or open air
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M, Ammonia 0.3M, Copper sulphate 0.03M

Test No.	Air Supply Methods	EDTA (M)
E-Air-1	Close	0.00
E-Air-2	Close	0.03
E-Air-3	Open	0.00
E-Air-4	Open	0.03

Results — Thiosulphate (M)

No.\ Time	0h	5h	24h	Cons. (kg/t)
E-Air-1	0.243	0.170	0.122	29.1
E-Air-2	0.243	0.200	0.147	22.5
E-Air-3	0.244	0.159	0.006	54.7
E-Air-4	0.250	0.176	0.025	50.4

Results — Metallurgical Balance

E-Air-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.77	0.44	79.59
Solid Residue	200	0.57	0.11	20.41
Calc. Head		2.78	0.56	100.00

E-Air-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.90	0.48	87.38
Solid Residue	200	0.34	0.07	12.62
Calc. Head		2.72	0.54	100.00

E-Air-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.60	0.40	71.40
Solid Residue	200	0.80	0.16	28.60
Calc. Head		2.81	0.56	100.00

E-Air-4	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.86	0.47	84.49
Solid Residue	200	0.43	0.09	15.51
Calc. Head		2.75	0.55	100.00

Effects of EDTA on Gold Leaching in Copper Ammina solution

Group No. : **E-CAEDTA** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Sep. 1999**

Purpose : To study the effect of EDTA concentration in gold leaching in copper tetra ammine solution

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 5th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	9.8
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M, Ammonia 0.3M, Copper tetra ammine 0.1g/250ml

Test No.	EDTA:Copper Tetra Ammine (M:M)	EDTA (M)
E-CAEDTA-1	0	0
E-CAEDTA-2	0.5	0.00020
E-CAEDTA-3	1	0.00040
E-CAEDTA-4	2	0.00080

Results — Thiosulphate (M)

No.\ Time	0h	5h	24h	Cons. (kg/t)
E-CAEDTA-1	0.296	0.194	0.132	37.8
E-CAEDTA-2	0.300	0.226	0.148	28.4
E-CAEDTA-3	0.300	0.228	0.156	27.9
E-CAEDTA-4	0.305	0.239	0.157	23.4

Results — Metallurgical Balance

E-CAEDTA-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.52	0.38	84.42
Solid Residue	164	0.43	0.07	15.58
Calc. Head		2.75	0.45	100.00

E-CAEDTA-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.66	0.42	85.72
Solid Residue	193.33	0.36	0.07	14.28
Calc. Head		2.51	0.48	100.00

E-CAEDTA-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.70	0.43	85.16
Solid Residue	199.88	0.37	0.07	14.84
Calc. Head		2.50	0.50	100.00

E-CAEDTA-4	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.02	0.50	83.50
Solid Residue	232.76	0.43	0.10	16.50
Calc. Head		2.60	0.60	100.00

Effects of EDTA Tiny Increment on Gold Leaching

Group No. : **E-EDTA7** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Dec. 1999**

Purpose : To study the effects of EDTA concentration in a finner range

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 4th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M, Copper sulphate 0.03, Ammonia 3M

Test No.	EDTA (M)
E-EDTA7-1	0.03
E-EDTA7-2	0.033
E-EDTA7-3	0.036
E-EDTA7-4	0.04

Results — Thiosulphate (M)

No.\ Time	0h	5h	24h	Cons. (kg/t)
E-EDTA7-1	0.300	0.232	0.180	22.5
E-EDTA7-2	0.300	0.231	0.185	21.5
E-EDTA7-3	0.300	0.235	0.190	20.6
E-EDTA7-4	0.300	0.236	0.205	17.8

Results — Metallurgical Balance

E-EDTA7-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.16	0.54	88.47
Solid Residue	200	0.35	0.07	11.53
Calc. Head		3.05	0.61	100.00

E-EDTA7-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.24	0.56	88.68
Solid Residue	200	0.36	0.07	11.32
Calc. Head		3.16	0.63	100.00

E-EDTA7-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.16	0.54	87.88
Solid Residue	200	0.37	0.07	12.12
Calc. Head		3.07	0.61	100.00

E-EDTA7-4	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.23	0.56	86.95
Solid Residue	200	0.42	0.08	13.05
Calc. Head		3.20	0.64	100.00

Effects of Copper-EDTA-Ammonia on Gold Leaching

Group No. : **E-EDTA6** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Sep. 1999**

Purpose : To study the effect of reagent strength in gold leaching when the ratio of Cu:EDTA:NH3 was kept constant

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 5th hour
F Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M

Test No.	Copper Sulphate (M)	Ammonia (M)	EDTA(M)
E-EDTA6-1	0.005	1	0.005
E-EDTA6-2	0.01	2	0.01
E-EDTA6-3	0.03	6	0.03

Results — Thiosulphate (M)

No.\ Time	0h	5h	24h	Cons. (kg/t)
E-EDTA6-1	0.301	0.223	0.163	26.7
E-EDTA6-2	0.286	0.220	0.170	23.2
E-EDTA6-3	0.294	0.233	0.182	21.4

Results — Metallurgical Balance

E-EDTA6-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.64	0.41	85.71
Solid Residue	192	0.36	0.07	14.29
Calc. Head		2.50	0.48	100.00

E-EDTA6-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.66	0.41	84.63
Solid Residue	195.32	0.39	0.08	15.37
Calc. Head		2.50	0.49	100.00

E-EDTA6-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.79	0.45	82.55
Solid Residue	199.35	0.47	0.09	17.45
Calc. Head		2.71	0.54	100.00

Effects of Thiosulphate on Gold Leaching in EDTA solution

Group No. : **E-EDTA5** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Sep. 1999**

Purpose : To study the effect of ammonia concentration on gold leaching in EDTA solution

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 5th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M, Copper sulphate 0.01M, EDTA 0.01M

Test No.	Ammoina
E-EDTA5-1	2
E-EDTA5-2	3
E-EDTA5-3	5

Results — Thiosulphate (M)

No.\ Time	0h	5h	24h	Cons. (kg/t)
E-EDTA5-1	0.301	0.235	0.181	22.9
E-EDTA5-2	0.301	0.235	0.191	20.5
E-EDTA5-3	0.286	0.220	0.170	23.2

Results — Metallurgical Balance

E-EDTA5-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.66	0.41	84.63
Solid Residue	195	0.39	0.08	15.37
Calc. Head		2.50	0.49	100.00

E-EDTA5-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.75	0.44	85.67
Solid Residue	199.88	0.37	0.07	14.33
Calc. Head		2.55	0.51	100.00

E-EDTA5-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.66	0.42	81.68
Solid Residue	195.64	0.48	0.09	18.32
Calc. Head		2.60	0.51	100.00

Effects of Thiosulphate on Gold Leaching in EDTA solution

Group No. : **E-EDTA4** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Sep. 1999**

Purpose : To study the effect of high thiosulphate gold leaching in EDTA solution

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 5th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Copper sulphate 0.03M, EDTA 0.03M, Ammonia 3M

Test No.	Thiosulphate (M)
E-EDTA4-1	0.3
E-EDTA4-2	0.5

Results — Thiosulphate (M)

No.\ Time	0h	5h	24h	Cons. (kg/t)
E-EDTA4-1	0.298	0.217	0.172	24.5
E-EDTA4-2	0.495	0.376	0.302	39.1

Results — Metallurgical Balance

E-EDTA4-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.74	0.44	87.26
Solid Residue	194	0.33	0.06	12.74
Calc. Head		2.58	0.50	100.00

E-EDTA4-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.80	0.45	90.02
Solid Residue	185.87	0.27	0.05	9.98
Calc. Head		2.69	0.50	100.00

Effects of Ammonia on Gold Leaching in EDTA solution

Group No. : **E-EDTA3** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Sep. 1999**

Purpose : To study the effects ammonia on gold leaching in EDTA solution

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 5th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M, Copper sulphate 0.03M, EDTA 0.03M

Test No.	Ammonia (M)
E-EDTA3-1	1
E-EDTA3-2	3
E-EDTA3-3	6

Results — Thiosulphate (M)

No.\ Time	0h	5h	24h	Cons. (kg/t)
E-EDTA3-1	0.298	0.217	0.172	24.5
E-EDTA3-2	0.274	0.214	0.164	23.2
E-EDTA3-3	0.286	0.238	0.189	19.3

Results — Metallurgical Balance

E-EDTA3-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.74	0.44	87.26
Solid Residue	194	0.33	0.06	12.74
Calc. Head		2.58	0.50	100.00

E-EDTA3-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.81	0.45	87.96
Solid Residue	193.5	0.32	0.06	12.04
Calc. Head		2.66	0.51	100.00

E-EDTA3-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.12	0.53	88.11
Solid Residue	196.35	0.37	0.07	11.89
Calc. Head		3.07	0.60	100.00

Effects of EDTA-Copper on Gold Leaching

Group No. : **E-EDTA2** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Sep. 1999**

Purpose : To study the effects of EDTA-Copper concentration on gold leaching

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 5th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M, Ammonia 3M

Test No.	Copper Sulphate (M)	EDTA (M)
E-EDTA2-1	0.01	0.01
E-EDTA2-2	0.03	0.03
E-EDTA2-3	0.1	0.1

Results — Thiosulphate (M)

No.\ Time	0h	5h	24h	Cons. (kg/t)
E-EDTA2-1	0.296	0.235	0.200	19.1
E-EDTA2-2	0.274	0.214	0.164	23.2
E-EDTA2-3	0.276	0.200	0.151	26.6

Results — Metallurgical Balance

E-EDTA2-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.83	0.46	89.31
Solid Residue	191	0.29	0.05	10.69
Calc. Head		2.68	0.51	100.00

E-EDTA2-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.81	0.45	87.96
Solid Residue	193.5	0.32	0.06	12.04
Calc. Head		2.66	0.51	100.00

E-EDTA2-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.72	0.43	88.05
Solid Residue	190.42	0.31	0.06	11.95
Calc. Head		2.57	0.49	100.00

Effects of EDTA on Gold Leaching

Group No. : **E-CA1** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Sep. 1999**

Purpose : To study the effects of EDTA concentration on gold leaching

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 5th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M, Copper sulphate 0.03, Ammonia 3M

Test No.	EDTA (M)
E-EDTA1-1	0.015
E-EDTA1-2	0.03
E-EDTA1-3	0.06

Results — Thiosulphate (M)

No.\ Time	0h	5h	24h	Cons. (kg/t)
E-EDTA1-1	0.278	0.198	0.131	32.1
E-EDTA1-2	0.274	0.214	0.164	23.2
E-EDTA1-3	0.288	0.230	0.194	19.2

Results — Metallurgical Balance

E-EDTA1-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.74	0.43	88.23
Solid Residue	185	0.31	0.06	11.77
Calc. Head		2.66	0.49	100.00

E-EDTA1-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.81	0.45	87.96
Solid Residue	193.5	0.32	0.06	12.04
Calc. Head		2.66	0.51	100.00

E-EDTA1-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.68	0.42	81.14
Solid Residue	191.14	0.51	0.10	18.86
Calc. Head		2.70	0.52	100.00

Effects of Ammonia-Copper-Ammine on Gold Leaching

Group No. : E-CA1 **Experimenter : Chen Xia** **Ore : Hope Brooke** **Oct. 1999**

Purpose : To study the effects of ammonia-copper-ammine on gold leaching

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 4th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	9.6~9.8
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M

Test No.	Copper Tetra Ammine (g)	Ammonia (M)
E-CA1-1	0.1	0.1
E-CA1-2	0.32	0.3
E-CA1-3	0.6	0.6

Results — Thiosulphate (M)

No.\ Time	0h	4h	24h	Cons. (kg/t)
E-CA1-1	0.274	0.235	0.161	22.8
E-CA1-2	0.282	0.220	0.166	22.7
E-CA1-3	0.268	0.188	0.156	23.6

Results — Metallurgical Balance

E-CA2-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.71	0.43	76.12
Solid Residue	202	0.66	0.13	23.88
Calc. Head		2.77	0.56	100.00

E-CA2-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.03	0.51	87.59
Solid Residue	203.6	0.35	0.07	12.41
Calc. Head		2.85	0.58	100.00

E-CA2-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.00	0.50	86.51
Solid Residue	198.88	0.39	0.08	13.49
Calc. Head		2.91	0.58	100.00

Effects of Ammonia on Gold Leaching by Copper Tetra Amine

Group No. : **E-CA2** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Oct. 1999**

Purpose : To study the effects of ammonia on gold leaching in copper tetra ammine solution

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 4th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	9.6~9.8
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M, Copper tetra ammine 0.1g/250ml

Test No.	Ammonia (M)
E-CA2-1	0.05
E-CA2-2	0.1
E-CA2-3	0.3
E-CA2-4	0.6

Results — Thiosulphate (M)

No.\ Time	0h	4h	24h	Cons. (kg/t)
E-CA2-1	0.277	0.241	0.185	18.6
E-CA2-2	0.274	0.235	0.161	22.8
E-CA2-3	0.267	0.220	0.159	22.7
E-CA2-4	0.269	0.214	0.166	21.7

Results — Metallurgical Balance

E-CA2-1	Amount mL, g	Assay, Au mg/L, g/t	Au Unit mg	Au Dis. %
Preg. solution	250	1.17	0.29	50.38
Solid Residue	201	1.44	0.29	49.62
Calc. Head		2.90	0.58	100.00

E-CA2-2	Amount mL, g	Assay, Au mg/L, g/t	Au Unit mg	Au Dis. %
Preg. solution	250	1.71	0.43	76.12
Solid Residue	202.02	0.66	0.13	23.88
Calc. Head		2.77	0.56	100.00

E-CA2-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.01	0.50	88.51
Solid Residue	200.36	0.33	0.07	11.49
Calc. Head		2.83	0.57	100.00

E-CA2-4	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.96	0.49	83.34
Solid Residue	198.25	0.49	0.10	16.66
Calc. Head		2.96	0.59	100.00

Effects of Copper Tetra Amine on Gold Leaching Performance

Group No. : **E-CA3** **Experimenter : Chen Xia** **Ore : Hope Brooke** **Oct. 1999**

Purpose : To study the effects of copper tetra ammine on gold extraction and thiosulphate stability

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass bottles
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 4th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	9.6~9.8
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M

Test No.	Copper Tetra Ammine (g)	Ammonia (M)
E-CA3-1	0.1	0.1
E-CA3-2	0.37	0.1
E-CA3-3	0.1	0.3
E-CA3-4	0.32	0.3
E-CA3-5	0.1	0.6
E-CA3-6	0.6	0.6

Results — Thiosulphate (M)

No.\Time	0h	4h	24h	Cons. (kg/t)
E-CA3-1	0.274	0.235	0.161	22.8
E-CA3-2	0.284	0.255	0.161	24.2
E-CA3-3	0.267	0.220	0.159	22.7
E-CA3-4	0.282	0.220	0.166	22.7
E-CA3-5	0.269	0.214	0.166	21.7
E-CA3-6	0.268	0.188	0.156	23.6

Results — Metallurgical Balance

E-CA3-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.71	0.43	76.12
Solid Residue	202	0.66	0.13	23.88
Calc. Head		2.77	0.56	100.00

E-CA3-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.83	0.46	78.25
Solid Residue	199.94	0.64	0.13	21.75
Calc. Head		2.93	0.59	100.00

E-CA3-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.01	0.50	88.51
Solid Residue	200.36	0.98	0.07	11.49
Calc. Head		2.83	0.57	100.00

E-CA3-4	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	2.03	0.51	87.59
Solid Residue	203.6	0.35	0.07	12.41
Calc. Head		2.85	0.58	100.00

E-CA3-5	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.96	0.49	83.34
Solid Residue	198.25	0.49	0.10	16.66
Calc. Head		2.96	0.59	100.00

E-CA3-6	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.77	0.44	82.25
Solid Residue	195	0.49	0.10	17.75
Calc. Head		2.76	0.54	100.00

Effects of Various Additives on Gold Leaching Performance

Group No. : E-Add Experimenter : Chen Xia Ore : Hope Brooke Sep. 1999

Purpose : To compare the effects of various additives on gold extraction and thiosulphate stability

Procedure :

A. Grind the ore, divide it into equal parts and fill samples into glass
B. Dissovle stable reagents in ammonia solutions, fill solutions in bottles
C. Add instable reagents, adjust solution volume/pH and seal the bottles
D. Keep the bottles rotating on rolls for 24 hours
E. Refresh the air in bottls at the 4th hour
F. Monitor the concentration of thiosulphate
G. Conduct zinc precipitaiton process if required
H. Filter the pulp after 24 hours and collect samples for assays
I. Conduct standard fire assay

Operation Conditions

Feed	200g
Pulp Density	44%
pH	10.2
Air	Air in a capped bottle
Grind	(-10 mesh sample) in a laboratary rod mill at 60% solid for 20min/kg
Size	85% -200m

Reagent Conditions and Variables

Thiosulphate 0.3M, Copper sulphate 0.03M, Ammonia 3M

Test No.	Addtive	Concen. (M)
E-Add-1	No	0
E-Add-2	Sulphate	0.1
E-Add-3	Sulphite	0.1
E-Add-4	Sulpur Dioxide	0.1
E-Add-5	Sulphide	0.1
E-Add-6	Bisulphite	0.1
E-Add-7	EDTA	0.03
E-Add-8	NTA	0.03
E-Add-9	Glycine	0.06

Results — Thiosulphate (M)

No.\ Time	0h	4h	24h	Cons. (kg/t)
E-Add-1	0.243	0.170	0.122	29.068
E-Add-2	0.250	0.182	0.123	29.177
E-Add-3	0.224	0.170	0.112	28.750
E-Add-4	0.224	0.178	0.122	26.139
E-Add-5	0.255	0.170	0.132	27.466
E-Add-6	0.245	0.191	0.123	28.522
E-Add-7	0.243	0.200	0.147	22.538
E-Add-8	0.251	0.203	0.156	21.808
E-Add-9	0.247	0.179	0.126	28.430

Results — Metallurgical Balance

E-Add-1	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.70	0.43	79.59

Solid Residue	192	0.57	0.11	20.41
Calc. Head		2.78	0.53	100.00

E-Add-2	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.88	0.47	87.06
Solid Residue	194.53	0.36	0.07	12.94
Calc. Head		2.78	0.54	100.00

E-Add-3	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.92	0.48	82.29
Solid Residue	195.76	0.53	0.10	17.71
Calc. Head		2.97	0.58	100.00

E-Add-4	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.67	0.42	84.21
Solid Residue	195.53	0.40	0.08	15.79
Calc. Head		2.54	0.50	100.00

E-Add-5	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.90	0.47	84.85
Solid Residue	196.9	0.43	0.08	15.15
Calc. Head		2.84	0.56	100.00

E-Add-6	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.77	0.44	82.25
Solid Residue	195	0.49	0.10	17.75
Calc. Head		2.76	0.54	100.00

E-Add-7	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.94	0.49	87.88
Solid Residue	196.99	0.34	0.07	12.12
Calc. Head		2.80	0.55	100.00

E-Add-8	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.91	0.48	87.23
Solid Residue	194.81	0.36	0.07	12.77
Calc. Head		2.81	0.55	100.00

E-Add-9	Amount	Assay, Au	Au Unit	Au Dis.
	mL, g	mg/L, g/t	mg	%
Preg. solution	250	1.85	0.46	84.29
Solid Residue	192.72	0.45	0.09	15.71
Calc. Head		2.85	0.55	100.00