

Gold Recovery from Copper-Gold Tailings by Ammoniacal Thiosulphate Leaching

Kamolwich Income^{1*}, Sirinat Boonpo², Thidarat Kruatian², Ponlayuth Sooksamiti¹ and Sukjit Kungwankunakorn²

¹Department of Primary Industries and Mines, Ministry of Industry, Bangkok, Thailand

²Department of Chemistry, Faculty of Science, Chiang Mai University, Chiang Mai, Thailand

Received: 14 October 2020, Revised: 11 February 2021, Accepted: 12 April 2021

Abstract

Ammoniacal thiosulphate leaching is a safer method to apply for gold leaching because it does not involve the use of cyanide. It has been found to be a better method than other leaching methods. It is non-toxic and environment-friendly for gold extraction. In this study, the method was developed especially for gold leaching from copper-gold tailings samples. Various factors such as copper(II) sulphate concentration, ammonium thiosulphate concentration, pH, solid-liquid ratio, temperature and rotation speed were studied to determine optimum conditions for leaching. It was found that the most suitable condition were 0.07 M copper(II) sulphate, 0.5 M ammonium thiosulphate, pH = 10, solid-liquid ratio = 1:10, room temperature (30 °C), rotation speed = 400 rpm and 5 h leaching time. Flame atomic absorption spectrometry was used to analyse the concentration of gold after the leaching process was performed. The performance of ammoniacal thiosulphate leaching method was evaluated by standard material No. ST 279. It was found that the precision of ammoniacal thiosulphate leaching method considered from relative standard deviation value was 2.28%. The accuracy which was considered from the recovery value was 97.63%. The detection limit of gold by flame atomic absorption spectrometry was 0.006 mg/l. The ammoniacal thiosulphate leaching method with optimum condition was applied for gold extraction from copper-gold tailings from northeastern part of Thailand. The results indicated that gold concentration from the ammoniacal thiosulphate leaching method was in the range of 65.52-89.50 g/t. Recovery by the ammoniacal thiosulphate leaching method was greater than 90% as was confirmed by the fire assay standard method.

Keywords: ammoniacal thiosulphate leaching; atomic absorption spectrometry; copper-gold tailings; fire assay; gold
DOI.....

*Corresponding author: Tel.: (+66) 53221385 Fax: (+66) 53225184
E-mail: Kamolwich_in@hotmail.com

1. Introduction

Gold holds a prestigious and highly special position in the periodic table when compared to other metals. For many centuries, it has been recognized as the most “noble” of metals due to its resistance towards most corrosive forces. It also has been known as King of the Metals because of its economic value. Gold is sophisticated, robust and mechanically malleable. It, furthermore, has beautiful color and sparkling appearance. It has long been considered as a useful and ideal material for culture and art, as well as for coin currency and jewelry. In more recent times, gold metal has become an important material for the electricity and electronics industry because of its high electrical and thermal conductivity [1]. It is not generally thought to be a homologue of the other two coinage metals in the periodic table, copper and silver as it possesses totally different oxidation states, oxidation potentials, coordination numbers and coordination geometries [2-4]. The atomic number of gold is $Z = 79$. Gold has only one stable isotope, which has an atomic mass of 197 [5]. The freezing and boiling points of gold are 1064°C and 3081°C , respectively. The density of pure gold is 19300 kg/m^3 in spite of the fact that the density of native gold typically is 15000 kg/m^3 . Gold is inert under the conditions of ambient pressure and temperature. Consequently, there are very few naturally occurring compounds of metal. Gold has a metallic luster. Its color is distinctively golden or deep yellow; however, it may be light yellow or orange/yellow with high contents of silver and copper, respectively. Pure gold is an excellent electrical and thermal conductor [6].

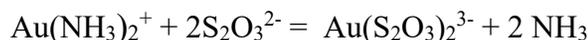
Gold is present in small amount in clays, pyrite and it is generally found in copper, silver, bismuth, zinc, lead, tellurium and antimony ores [7]. Copper-gold tailings involves the removal of gold which contains in copper ores and iron ores during the floatation process of gold mining. Content of gold in copper ores is related to the copper content. Copper ores with a high percentage of copper generally present a high percentage of gold. In general, copper ores contain gold between 2 and 30 g/t. A high amount of gold, in the range of 10- 30 g/t, is usually found in copper ores that contain 10-15% of copper. Other components in ores are iron and rocks. The leaching of gold is very interesting for study owing to the high value of gold although it is contained in small amount in copper ores. Previous studies focused on the cyanide leaching method, which was used for leaching of gold in a variety of samples [7-11].

In the cyanidation method, copper and iron must be removed before the leaching process as the metals can also react with cyanide, which interferes with gold leaching. Cyanide is toxic to human health and aquatic life even at low concentrations [12]. Exposure to cyanide leads to various thyrotoxic and neuropathic conditions in humans [13], and thus the concentration of cyanide in water is limited to 0.2 mg/l by WHO [14]. Moreover, the difficulty of gold leaching, cost of gold extraction and process time of this method have made it of value to investigate other methods of gold extraction from tailings [15].

The process of ammoniacal thiosulphate leaching is based on the removing of gold out of gold bearing ores without toxic cyanide as a reagent. The ammoniacal thiosulphate leaching method has many advantages when compared with cyanidation method. It offers lower toxicity and greater efficiency for treatment of gold deposits associated with preg-robbing ores. During the leaching process of gold by the ammoniacal thiosulphate method, the chemical reactions involved are dissolution, oxidation and complexation. The chemistry of the ammoniacal thiosulfate system for extraction of gold involves the relationship of three major components which are thiosulfate, ammonia and copper. Gold is stabilized by thiosulfate, whilst copper and ammonia speed up the leaching reaction [16-18]. Generally, when a mild oxidant such as oxygen appears in the reaction, gold dissolves slowly in alkaline solution of thiosulphate. The alkaline solution functions to prevent the decomposition at low pH of thiosulphate. The dissolution reaction [19] can be written as:



The dissolution of gold in thiosulfate is blocked under conditions of a lack of ammonia by the coating of sulfur on the gold surface that is the cause of decomposition of thiosulfate. This problem is prevented by ammonia because ammonia is absorbed on the surfaces of gold over thiosulfate. Hence, gold is transferred into the solution in the form of amine complex [20]. Then, it is replaced by thiosulfate as presented below.



However, the main role of ammonia in thiosulfate system is to stabilize the oxidant (copper) by forming copper (II) amine complexes which speed up the dissolution of gold as shown below [21].



The presence of ammonia hinders the dissolution of iron oxides, silica, silicates, and carbonates, which are the most common gangue minerals found in gold bearing ores. An oxidant is needed to oxidize metallic gold to gold(I) in the thiosulphate system, and it is shown in the solution as copper(II) ions. Various oxidants including oxygen, hydrogen peroxide, ferric ion, ozone, and formamidine disulfide, were used in previous studies [22]. Gold in the form of an anionic aurocomplex was dissolved by ammonium thiosulphate, which is stable over a wide range of pH and Eh values. The dissolution reaction for gold can be written as:



To understand the chemical reactions during the leaching process, the Eh-pH equilibrium was investigated in previous studies. The studies reported the involvement of Eh and pH in the predominant species of gold in the system in which $[\text{Au}(\text{S}_2\text{O}_3)_2]^{3-}$ and $[\text{Au}(\text{NH}_3)_2]^+$ were concerned. Moreover, the pH values were significantly changed by changes in the thiosulfate or ammonia concentration that had an effect on the presence of gold species. At conditions above pH of 9, the predominant species of gold in the system was $[\text{Au}(\text{S}_2\text{O}_3)_2]^{3-}$ (a higher stability) rather than $[\text{Au}(\text{NH}_3)_2]^+$ [23, 24]. The dissolution of gold was also significantly influenced by the pH because of the occurrence of different ratios of $\text{NH}_3/\text{NH}_4^+$ that related to the stability zone of $\text{Cu}(\text{NH}_3)_4^{2+}$ [25]. Besides, there was a report about the effect of the reagent concentration on gold leaching. At low concentrations of reagent, the copper ammonium complex is stable in narrow pH region and at high concentrations of reagent, the copper ammonium complex is stable in a broader pH range [17]. From the above data, it can be concluded that the efficiency of gold leaching by ammoniacal thiosulfate system significantly depends on many factors. Therefore, the optimal conditions should be investigated in order to enhance the efficiency of extraction.

This study has focused on the extraction of gold from copper-gold tailings by the ammoniacal thiosulphate leaching method on laboratory scale, a method that is safer to use for gold extraction because it takes place without cyanide. The optimum conditions for gold extraction by the ammoniacal thiosulphate leaching method for copper-gold tailings sample were studied specifically. The recoveries of gold by the ammoniacal thiosulphate leaching were confirmed with results of the recoveries from the fire assay standard method. The result of this study indicate that the developed ammoniacal thiosulphate leaching method is efficient to be applied for gold extraction from copper-gold tailing samples.

2. Materials and Methods

2.1 Apparatus and reagents

A Varian SpectrAA 220FS atomic absorption spectrometer from Varian (Varian, Australia) was used for Au measurement. These conditions are given in Table 1. Powder X-ray diffraction pattern of sample was obtained from 5 to 55 in 2θ by X-ray diffractometer (XRD) with cobalt $K\alpha$ radiation (BTX II Benchtop XRD, Olympus). A Jones riffle sampler from Tyler (USA) and roll crusher from Retsch GmbH (Germany) were used for sample preparation. A crucible furnace was used for sample fusion.

Table 1. Measurement conditions for AAS

Parameters	Conditions
Wavelength (nm)	242.4
Slit width (nm)	1.0
Fuel	Acetylene
Oxidant	Air
Flame stoichiometry	Oxidizing

The copper-gold tailing samples that were used in both fire assay and ammoniacal thiosulfate method were obtained from gold mining process at the Phutubfa gold mine in Wangsaphung district, Loei province, Thailand. The copper concentrate, standard material No. ST 279 (Au = 7.18 g/t), was obtained from Gannet, Australia and was used to evaluate the efficiency of gold leaching by ammoniacal thiosulfate method. Ammonium thiosulphate was obtained from Merck, Germany. Copper sulphate pentahydrate was from Fluka, USA. The 1000 $\mu\text{g/ml}$ of Au standard solution was obtained from BDH Chemicals, England. Working standard solutions were prepared by appropriate dilution of the stock standard solution. All other reagents were of analytical-reagent grade (E. Merck, Darmstadt, Germany) and all solutions were prepared with deionized water.

2.2 Preparation of copper-gold tailing samples

For the sampling of copper-gold tailing samples, systematic random sampling was applied for this study. Approximately 2-2.5 kg in total of sample was collected from 4 different points of depth of the big bag containing copper-gold tailings using a grain solid sample probe. Then, the sample amount was reduced by two sampling processes, cone and quartering, as well as sample division to 600 g. After that, the copper-gold tailing samples were set by using a Jones Riffle sampler and dried at 104°C for 2 h. The dried samples were then ground by roll crushers. Finally, the ground samples were sieved into the size fraction of 150 μm [26] and stored in sample bottles.

2.3 Analysis of mineralogical species in copper-gold tailings by X-ray diffraction technique

Copper-gold tailings samples were packed into sample cells before the samples were analyzed. X-ray diffractometry was performed on a BTX II X-ray diffraction analyzer equipped with a cobalt

anode. The conditions of operation are shown in Table 2. The results were identified based on X Powder (search-match program) and the database of International Center for Diffraction Data (ICDD).

Table 2. X-ray diffraction instrument settings and analytical conditions

Parameters	Conditions
Voltage (kV)	30.5
Start 2θ (degree)	5
Step size (degree)	0.05
Divergence slit (degree)	1
Current (mA)	0.35
Stop 2θ (degree)	55
Time/step (second)	10
Anti-scattering slit (degree)	1

2.4 Determination of gold by fire assay standard method

Five grams of the copper-gold tailing samples were placed in a plastic bag with 50 g PbO and about 36.5 g of a flux containing 20 g Na_2CO_3 , 10 g $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$, 5 g SiO_2 and 1.5 g flour. After combining, the plastic bag with mixed components was put into a fire clay crucible. Then, Ag as silver foil was added. The crucible was brought into a preheated furnace and fused at 1100°C for 1 h. The molten contents were then poured into an iron mold to cool. Pb regulus containing the analyses was separated from slag and cleaned by hammering and brushing. Magnesite cupels were preheated in a furnace at 950°C . After that, Pb regulus was put on a cupel which was allow to remain in the furnace until all oxidized lead had been absorbed by the cupel. A dofe was taken out of each cupel after cooling, hammered flat to speed up dissolution, and then transferred into a 10 ml porcelain crucible. The dofe bead was parted with HNO_3 (1:7 %v/v) and HNO_3 (3:1 %v/v) to eliminate silver and other impurities from the gold. The gold was washed with NH_4OH (1:9 %v/v) and dissolved with 5 ml of aqua regia in 50 ml beaker. After the gold had dissolved, the volume of the solution was made up to 50 ml with diluted HCl. After that, the prepared solution was analyzed by atomic absorption spectrometer, using the Varian SpectrAA 220FS instrument with an air-acetylene flame, to determine Au concentration. This experiment was repeated three times [27].

2.5 Evaluating performance of the ammoniacal thiosulphate leaching

The analysis of standard material No. ST 279 was carried out ten times to evaluate the precision of ammoniacal thiosulphate leaching method. The relative standard deviation was calculated. The analysis of standard material No. ST 279 was performed ten times to evaluate the accuracy of the ammoniacal thiosulphate leaching method. The results were calculated as the percentage of recovery. Limit of detection (LOD) of flame atomic absorption spectrometer instrument for determination of gold was determined by analysis of blank samples ten times. LOD was calculated using 3SD.

2.6 Extraction of gold in copper-gold tailings by ammoniacal thiosulphate leaching

To prepare the leaching solution, the dissolution of the appropriate chemicals in deionized water to the required concentration was conducted. A weighed amount of ammonium thiosulphate was dissolved in water. Then, the accurate volume of a solution of copper(II) sulphate in aqueous ammonia was added. Finally, the pH of the solution was adjusted by applying aqueous ammonia [25]. Each experiment was conducted in a 250 ml Erlenmeyer flask which contained copper-gold tailings mixed with the ammoniacal thiosulphate, which was then placed on a magnetic stirrer as shown in Figure 1. The solid particles were kept in suspension through the use of a mechanical stirrer. During a total retention time of 5 h, samples were taken continually at fixed intervals. The gold concentration in the leaching solutions was analyzed by flame atomic absorption spectrometry. The experiment was repeated three times.

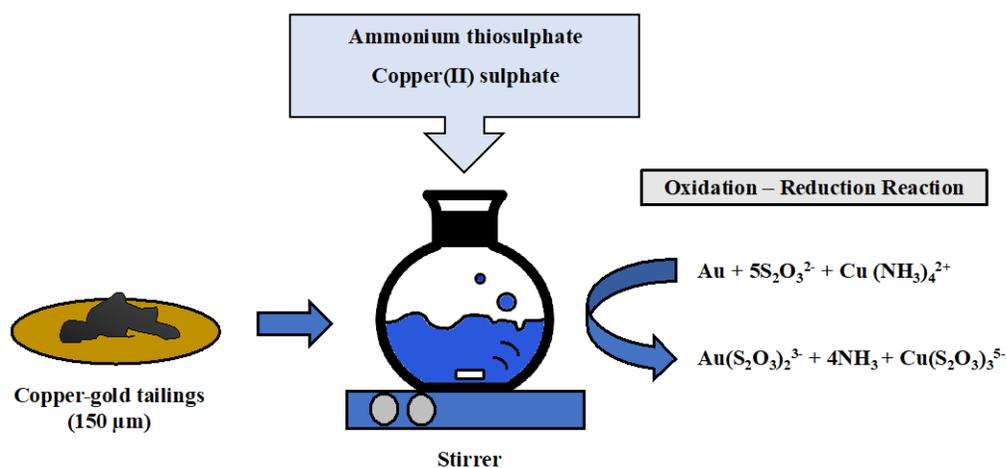


Figure 1. The ammoniacal thiosulphate leaching of gold in copper-gold tailings

3. Results and Discussion

3.1 Mineralogical species in copper-gold tailings by X-ray diffraction

The X-ray diffraction results of TK54-01 copper-gold tailings sample, which contained 82.04 g/t of gold (Analysis with fire assay standard method), presented the spectral patterns of chalcopyrite (CuFeS_2), pyrite (FeS_2), pyrrhotite (Fe_{1-x}S , $x = 0-0.2$) and quartz (SiO_2) as shown in Figure 2. The results indicated that copper-gold tailings were composed of chalcopyrite, pyrite, pyrrhotite and quartz.

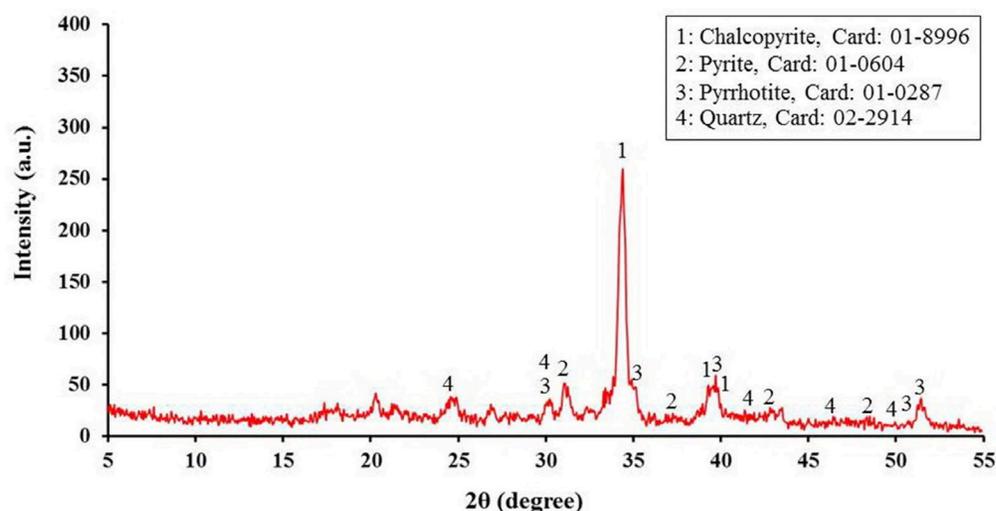


Figure 2. X-ray diffraction pattern of copper-gold tailings sample (TK54-01)

3.2 Evaluating performance of the ammoniacal thiosulphate leaching

The precision of the ammoniacal thiosulphate leaching method was studied by analysis of standard material No. ST 279 ten times. The results showed that the precision with replicative analyses, expressed as the relative standard deviation (%RSD), was found to be 2.28% which was less than 5%. This indicated that the ammoniacal thiosulphate leaching method provided good repeatability for gold under optimum conditions. The accuracy was evaluated by analysis of standard material No. ST 279 ten times. The results were in a good agreement with certified values. The recovery value was found to be 97.63%, which was higher than 95%. Hence, the ammoniacal thiosulphate leaching method is accurate. The flame atomic absorption spectrometric system programmatically generated the calibration curve. It was plotted and shown absorbance versus gold concentration. The linear range of the calibration curve was in the range of 2-10 mg/l. The calibration equation was $y = 0.036x + 0.0028$, and R^2 was 0.9995. Sensitivity, defined as slope of regression line, was 0.036 ppm. Limit of detection (LOD) was defined as concentration corresponding to 3SD of ten blank signals. Limit of detection of gold in flame atomic absorption spectrometry was found to be 0.006 mg/l.

3.3 Optimization of gold extraction conditions by ammoniacal thiosulphate leaching

The gold extraction method was developed using ammoniacal thiosulphate leaching and gold was determined by flame atomic absorption spectrometry. The experimental parameters were analyzed three times. The optimum parameter of ammoniacal thiosulphate leaching for gold extraction was very important to study. Several factors relevant to leaching efficiency were studied and optimized. Analytical factors, copper(II) sulphate concentration, ammonium thiosulphate concentration, pH, solid-liquid ratio, temperature and rotation speed on gold leaching were investigated for quantitative recovery of gold.

3.3.1 Effect of copper(II) sulphate concentration on gold leaching

The influence of Copper(II) sulphate on gold leaching was studied. The results are shown in Figure 3. Copper(II) sulphate concentration was varied from 0.01-0.09 M. Constant experimental conditions were 0.5 M ammonium thiosulphate, pH = 10, solid-liquid ratio = 1:10, room temperature (30°C) and rotation speed = 400 rpm. As shown in Figure 3, increasing copper(II) sulphate concentration up to 0.07 M shifted gold concentration-time curves to higher values (66.68 ± 2.73 g/t). However, above the aforementioned concentration, gold leaching recoveries plummeted to lower values. The major reason was that increasing Cu^{2+} ion concentration decreased the stability region of the $\text{Cu}(\text{NH}_3)_4^{2+}$ complex. The process led to a broadened stability region of solid copper compounds including, Cu_2O , CuO , Cu_2S and CuS . Thus, an increment of copper ion concentration led to formation of solid copper compounds by having higher consumption of thiosulphate as a result of changing Eh-pH equilibrium of the system [28].

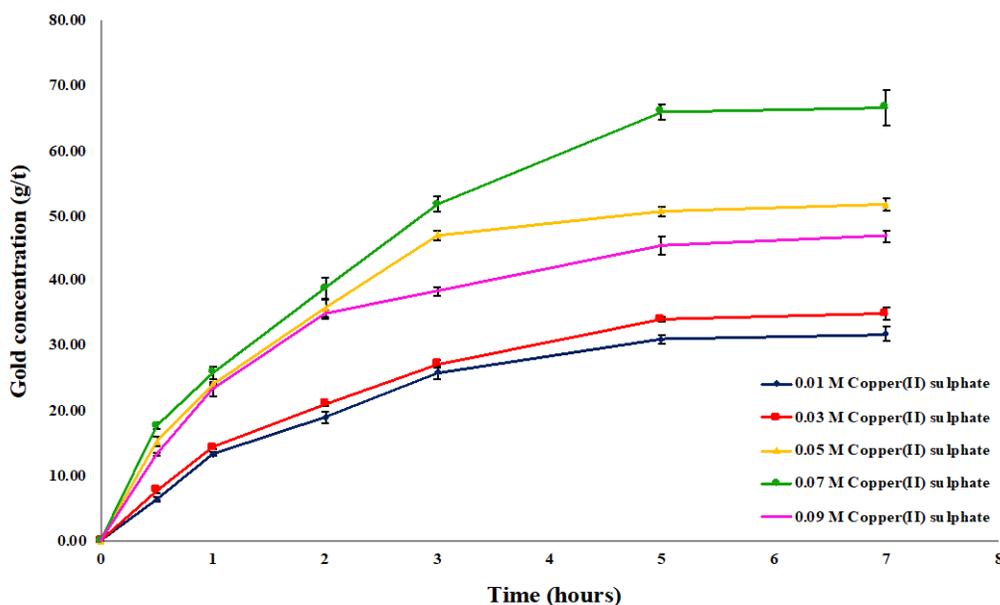


Figure 3. Effect of copper(II) sulphate concentration on gold leaching

3.3.2 Effect of ammonium thiosulphate concentration on gold leaching

Ammonium thiosulphate influence on gold leaching was examined. The results are shown in Figure 4. Ammonium thiosulphate concentration was varied from 0.1-0.9 M whilst the constant experimental conditions were 0.07 M copper (II) sulphate, pH = 10, solid-liquid ratio = 1:10, room temperature (30°C) and rotation speed = 400 rpm. Recovery of gold was enhanced by increasing ammonium thiosulphate concentration up to 0.5 M (66.68 ± 2.73 g/t) as shown in Figure 4, but a negligible effect on gold dissolution was obtained at higher ammonium thiosulphate concentrations. Increasing concentration of ammonium thiosulphate is attributable to a wider stability region of $\text{Cu}(\text{S}_2\text{O}_3)_3^{5-}$ complex because the change of thiosulfate or ammonia concentration has an effect in the pH values which influence the occurring of gold species in the

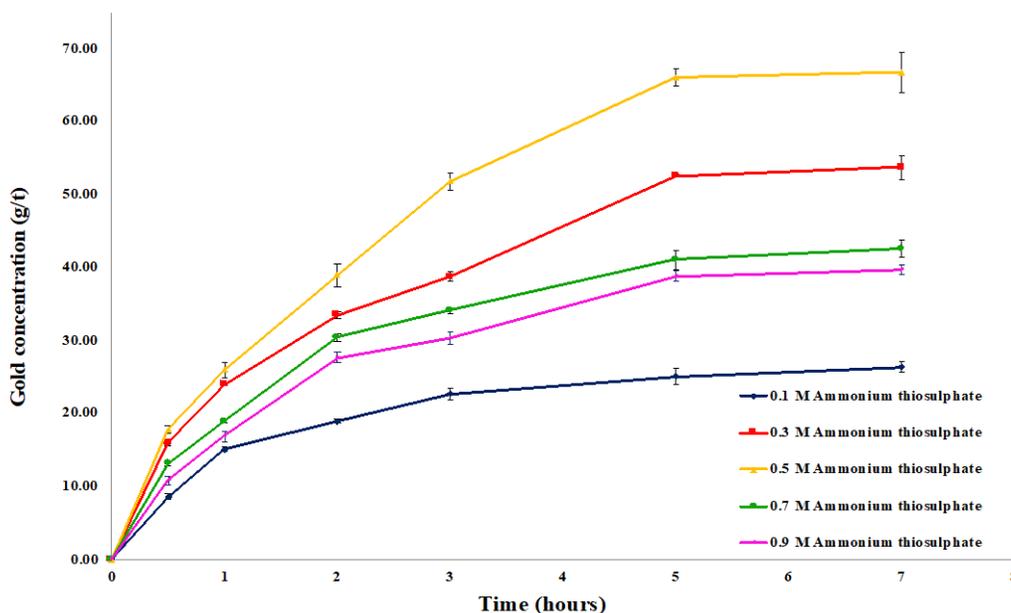


Figure 4. Effect of ammonium thiosulphate concentration on gold leaching

system as explained in Eh-pH diagram in the previous study [23]. This result revealed that the stability region of $\text{Cu}(\text{NH}_3)_4^{2+}$ complex in leach solution continuously decreased. In all cases, the rate of gold leaching increased slowly after 5 h of reaction [25].

3.3.3 Effect of pH on gold leaching

The previous studied reported that pH affected the predominant species of gold in the ammoniacal thiosulphate system. At different pH, different ratio of $[\text{Au}(\text{S}_2\text{O}_3)_2]^{3-}$ and $[\text{Au}(\text{NH}_3)_2]^+$ are present in the system, and these have an effect on the leaching of gold. Moreover, the occurrence of $\text{Cu}(\text{NH}_3)_4^{2+}$, which is an oxidant in the system, needs suitable pH condition [23]. Therefore, this parameter should be investigated. The influence of pH on gold leaching was scrutinized, and the outcomes are illustrated in Figure 5. In these experiments, pH was varied from 9-11 while constant experimental conditions were 0.07 M copper (II) sulphate, 0.5 M ammonium thiosulphate, solid-liquid ratio = 1:10, room temperature (30°C) and rotation speed = 400 rpm. The results indicated that pH of 10 shifted gold concentration-time curves to the highest values. This pH value was considered the most suitable condition in this study. Gold concentration decreased when pH was above pH 10. High pH values reduced the thermodynamic stability region of $\text{Cu}(\text{S}_2\text{O}_3)_3^{5-}$ and $\text{Cu}(\text{NH}_3)_4^{2+}$. Hence, this process resulted in lower gold leaching recoveries because the thermodynamic stability regions of solid copper species such as CuO and Cu_2O were widened [29]. Additionally, copper appeared in solid $(\text{NH}_4)_5\text{Cu}(\text{S}_2\text{O}_3)_3$ form. The solid reduced the oxidant activity of copper tetraammine complex and covered the surface of mineral, hindering thiosulphate attack [28].

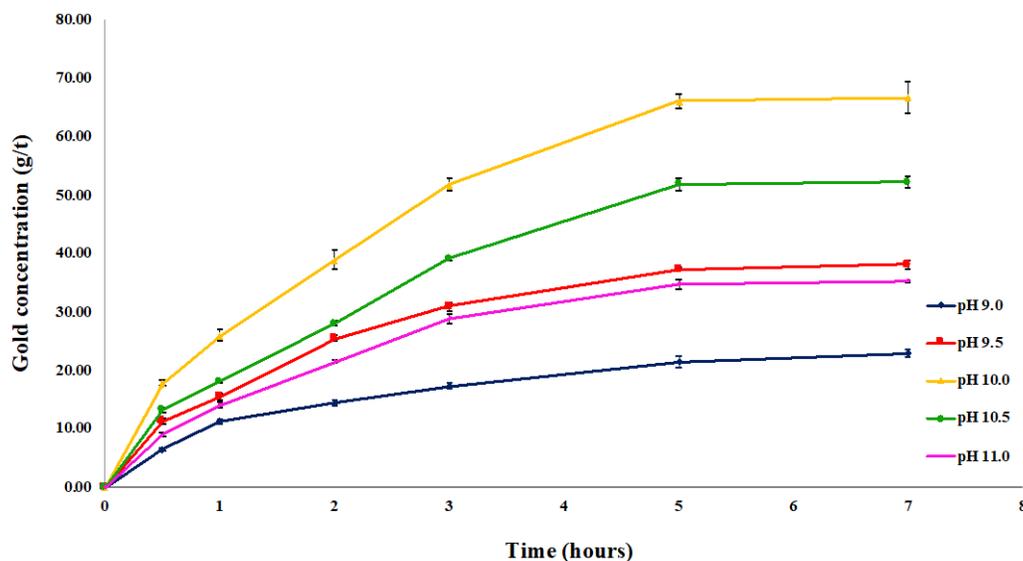


Figure 5. Effect of pH on gold leaching

3.3.4 Effect of solid-liquid ratio on gold leaching

The influence of solid-liquid ratio on gold leaching was investigated and the results are shown in Figure 6. The solid-liquid ratio is the ratio of copper-gold tailings to leach solution. Solid-liquid ratios (1:20, 1:10, 1:5, 3:10 and 2:5) were considered. Constant experimental conditions were 0.07 M copper (II) sulphate, 0.5 M ammonium thiosulphate, pH = 10, room temperature (30 °C) and rotation speed = 400 rpm. As illustrated in Figure 6, the solid-liquid ratios of 1:10 and 1:20 provided the highest gold concentrations. However, higher solid-liquid ratios above 1:10 led to lower gold concentration. The following two factors may have contributed to the decreasing of gold concentration. First, at higher solid-liquid ratio, leach solution concentration may not have been high enough to leach copper-gold tailings effectively; second, at high solid-liquid ratios, crowding of particles occurred resulting in more reduced contact with solution than particle-particle contact, thereby reducing leaching [30]. The solid-liquid ratios of 1:10 and 1:20 were shown to have similar leaching efficiency. Finally, only 1:10 ratio was selected to be used because of its better leaching solution than that of 1:20 ratio.

3.3.5 Effect of temperature on gold leaching

The influence of temperature on gold leaching was investigated and the results are shown in Figure 7. Temperature was varied from room temperature (30°C) to 70°C while the constant experimental conditions were 0.07 M copper(II) sulphate, 0.5 M ammonium thiosulphate, pH = 10, solid-liquid ratio = 1:10 and rotation speed = 400 rpm. As shown in Figure 7, insignificant differences of gold recovery with temperature between 30 and 70°C were observed. A previous report indicated that the temperature had an important role in the reaction rate of gold as it was involved in the chemical reaction speed [31]. However, that research was done over a short period of time (5 min) for leaching. In this study, a long period of time (5 h) was operated to get a high leaching efficiency, which was the purpose of this study. The reason why the increase of

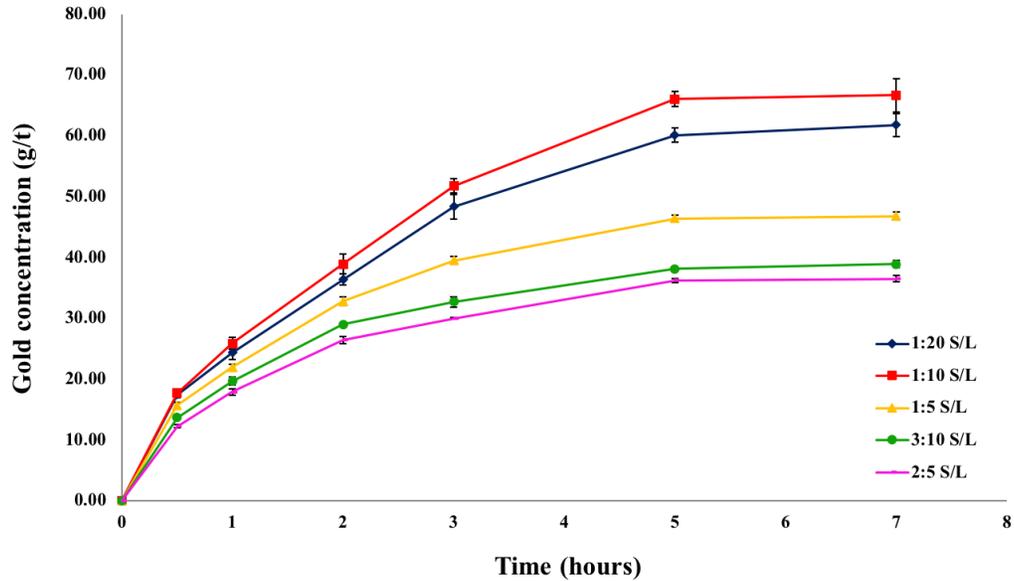


Figure 6. Effect of solid-liquid ratio on gold leaching

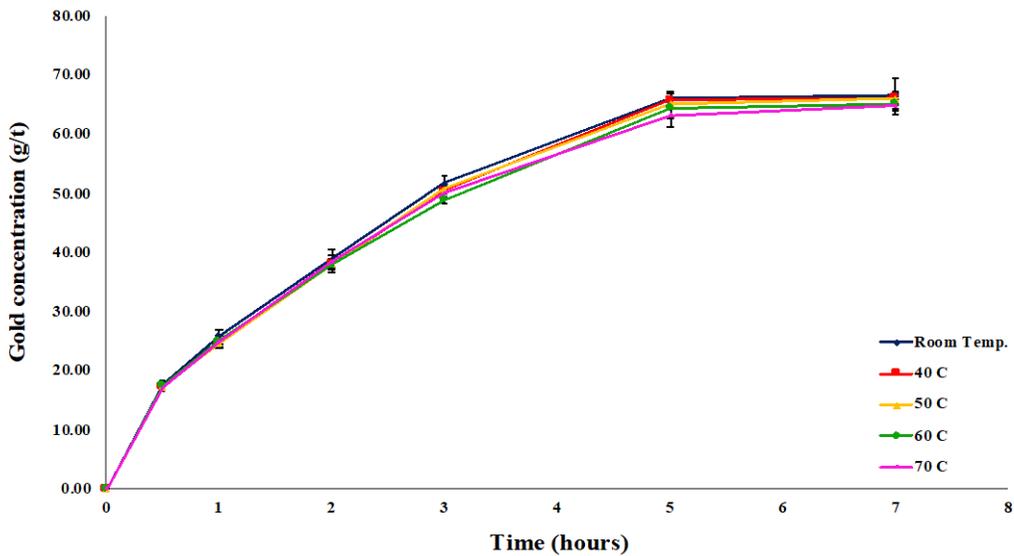


Figure 7. Effect of temperature on gold leaching

temperature did not have much effect on gold leaching recovery might be due to the use of a long period of time (5 h). This long leaching time was enough to compete for the reaction of gold leaching at 30-70°C. Hence, room temperature (30°C) was considered to be optimum for gold leaching by this method.

3.3.6 Effect of rotation speed on gold leaching

The influence of rotation speed on gold leaching was investigated and the results are shown in Figure 8. Rotation speed was varied from 300-700 rpm, while the constant experimental conditions were 0.07 M copper (II) sulphate, 0.5 M ammonium thiosulphate, pH = 10, solid-liquid ratio = 1:10 and room temperature (30°C). It is evident from Figure 8 that gold leaching increased with an increment of rpm from 300-400 rpm; however, beyond 400 rpm, the leaching of gold was decreased. It can be explicitly seen that speeds of rotation beyond 400 rpm caused turbulence that induced small fluctuations in pH and Eh values in the system which may have an impact on leaching performance as described by Rath *et al.* [30].

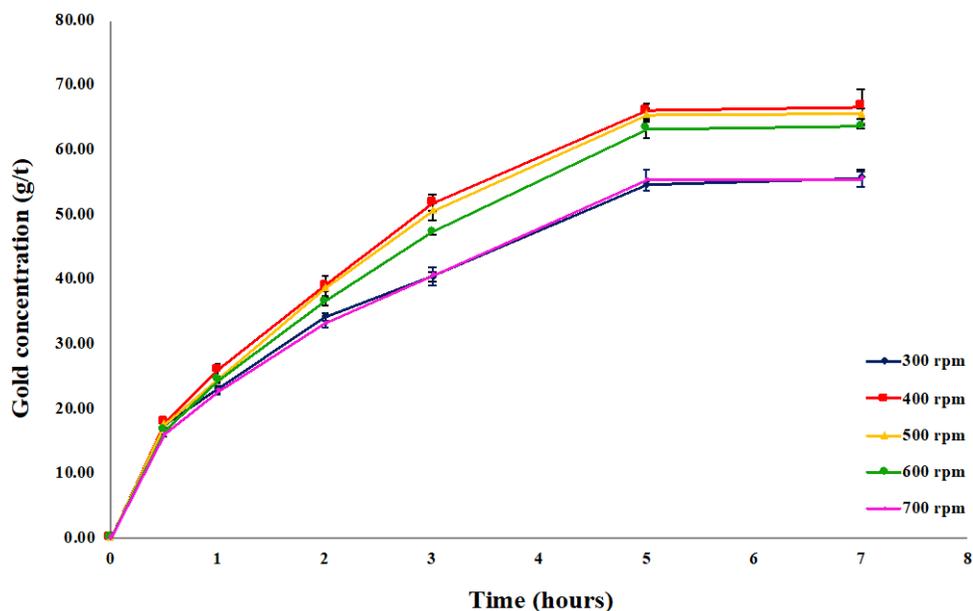


Figure 8. Effect of rotation speed on gold leaching

3.4 Determination of gold in copper-gold tailing samples by fire assay standard method

Copper-gold tailings samples were collected from the Phutubfa gold mine in Wang Saphung district, Loei province, Thailand. Samples were preconcentrated following the proposed method. Then, the analyte in solution samples was detected by flame atomic absorption spectrometry. This experiment was performed in triplicate for each sample. The results in Table 3 show that the concentrations of gold in studied copper-gold tailings samples were in the range of 71.93-92.46 g/t. Precision was considered from relative standard deviation values ($n = 8$). It was found that relative standard deviation values of less than 5% were considered satisfactory.

3.5 Extraction of gold in copper-gold tailing samples by ammoniacal thiosulphate leaching

The optimized method was applied to determine the gold in copper-gold tailing samples. Samples were analyzed for gold by the ammoniacal thiosulphate leaching method three times. The results in Table 3 indicate that the concentrations of gold in copper-gold tailing samples were between 65.52-89.50 g/t. Precision was considered from relative standard deviation values ($n = 8$). It was found that relative standard deviation values of less than 5% were considerably satisfactory.

Table 3. Comparison of ammoniacal thiosulphate leaching method with fire assay standard method

Sample	Au concentration (g/t)				% Recovery Au
	Fire assay*	%RSD	Ammoniacal thiosulphate leaching*	%RSD	
TK54-01	82.04±1.10	1.29	80.05±1.51	1.89	97.57
TK54-02	84.32±1.12	1.33	80.67±1.92	2.38	95.67
TK54-03	92.46±1.43	1.55	89.50±2.43	2.72	96.80
TK54-04	80.69±0.91	1.13	77.06±2.51	3.26	95.50
TK54-05	78.16±0.82	1.05	71.84±2.59	3.61	91.91
TK54-06	72.06±2.52	3.50	65.52±1.96	2.99	90.92
TK55-01	89.87±1.73	1.93	81.42±1.28	1.57	90.60
TK55-02	75.63±1.40	1.85	70.56±1.49	2.11	93.30
TK55-03	86.95±0.97	1.12	82.21±2.19	2.66	94.55
TK55-04	71.93±1.58	2.20	68.33±2.76	4.04	95.00
TK55-05	76.01±0.57	0.75	71.69±2.60	3.63	94.32
TK55-06	74.54±1.32	1.77	70.62±1.34	1.90	94.74

*N=3

3.6 Evaluation of gold recovery by ammoniacal thiosulphate leaching with the result from fire assay standard method

The recovery of gold from this method was analyzed to evaluate the efficiency of gold extraction in copper-gold tailings by ammoniacal thiosulfate leaching. Flame atomic absorption spectrometry is a common technique for detecting gold at low concentration. This technique has high sensitivity, selectivity and much less interference. The gold recoveries of each sample by ammoniacal thiosulfate leaching method and fire assay standard method were investigated and compared. The results are shown in Table 3. If fire assay standard method results were assumed to represent 100% recovery of gold, we obtained recoveries greater than 90% for all samples by

ammoniacal thiosulphate leaching method. A good agreement was obtained from acceptable percent recovery. These results confirmed the validity of our proposed method. This study showed that ammoniacal thiosulphate leaching method to be an alternative extraction method as it provided good recoveries for gold extraction from copper-gold tailings.

4. Conclusions

In this study, the most suitable conditions for gold leaching using the ammoniacal thiosulphate leaching were obtained at 0.07 M copper(II) sulphate, 0.5 M ammonium thiosulphate, pH 10, solid-liquid ratio = 1:10, room temperature (30°C), rotation speed = 400 rpm, and about 5 h of leaching. The precision of ammoniacal thiosulphate leaching method was considered from %RSD values. It was found to be 2.28% which was less than 5%, the maximum value of acceptable relative standard deviation. This indicated that ammoniacal thiosulphate leaching method provided good repeatability for gold under the optimum conditions. Accuracy was considered from the results in comparison with true values of standard material No. ST 279. The achieved results were consistent with certified values. Recovery value was equal to 97.63% which was higher than 95%, the minimum value of acceptable percentage recovery. The detection limit of gold in flame atomic absorption spectrometry, which is defined as the concentration corresponding to 3SD of ten blank signals, was found to be 0.006 mg/l. The ammoniacal thiosulphate leaching method and fire assay standard method were performed for gold determination. From the results, if fire assay standard method results were assumed to represent 100% recovery of gold, we should obtain recoveries greater than 90% for all samples by the ammoniacal thiosulphate leaching method. A good agreement was obtained with the acceptable percent recovery. Therefore, this study shows that the ammoniacal thiosulphate leaching method is an alternative to the standard method of fire assay. It gives good recoveries for gold in copper-gold tailings. According to results from the study, optimum conditions may enhance gold leaching. Furthermore, this method can be applied in the mine industry because of its environment-friendly aspects.

5. Acknowledgements

The department of Primary Industries and Mines, Ministry of Industry is gratefully acknowledged. We would also like to thank the Department of Chemistry, Faculty of Science, Chiang Mai University for the research support.

References

- [1] Schmidbaur, H., 1999. *Gold-Progress in Chemistry, Biochemistry and Technology*. Chichester: John Wiley&Sons.
- [2] Puddephatt, R.J., 1978. *The Chemistry of Gold*. Amsterdam: Elsevier.
- [3] Rapsom, W.S. and Groenewald, T., 1978. *Gold Usage*. London: Academic Press.
- [4] Schmidbaur, H., 1990. The fascinating implications of new results in gold chemistry. *Gold Bulletin*, 23(1), 11-21.
- [5] Schmidbaur, H., Cronje, S., Djordjevic, B. and Schuster, O., 2005. Understanding gold chemistry through relativity. *Chemical Physics*, 311(1-2), 151-161.

- [6] Marsden, J.O. and House, C.I., 2006. *The Chemistry of Gold Extraction*. 2nd ed. Littleton: Society for Mining, Metallurgy, and Exploration, Inc. (SME).
- [7] Petrovic, N., Budelan, D., Cokic, S. and Nestic, B., 2001. The determination of the content of gold and silver in geological samples. *Journal of the Serbian Chemical Society*, 66(1), 45-52.
- [8] Estay, H., Carvajal, P., Gonzalez, K., Yanez, H., Bustos, W., Castro, S. and Arriagada, F., 2013. Cyanide leaching of copper-gold-silver ores. *5th International Seminar on Process Hydrometallurgy*, Santiago, Chile, July 10-12, 2013, 153-160.
- [9] Oraby, E., Esksteen, J. and Tanda, B., 2017. Gold and copper leaching from gold-copper ores and concentrates using a synergistic lixiviant mixture of glycine and cyanide. *Hydrometallurgy*, 169, 339-345.
- [10] Neelameggham, N.R., Alam, S., Oosterhof, H., Jha, A., Dreisinger, D. and Wang, S., 2015. *Rare Metal Technology 2015*. Cham.: Springer.
- [11] Anderson, C., 2012. Fundamentals of the analysis of gold, silver and platinum group metals. *Proceedings of 36th International Precious Metals Institute; a Sure Bet-World Economics Affect Precious Metals*, Las Vegas, U.S.A., 2012, 190-216.
- [12] Kwaansa-Ansah, E.E., Amenofe, L.P., Armah, E.K. and Opoku, F., 2017. Human health risk assessment of cyanide levels in water and tuber crops from Kenyasi, a mining community in the Brong Ahafo Region of Ghana. *International Journal of Food Contamination*, 4(16), <https://doi.org/10.1186/s40550-017-0061-y>
- [13] Dube, P.N. and Hosetti, B.B., 2010. Behavior surveillance and oxygen consumption in the freshwater fish *Labeo rohita* (Hamilton) exposed to sodium cyanide. *Biotechnology in Animal Husbandry*, 26(1-2), 91-103
- [14] Wilson, J., 1983. Cyanide in human disease: A review of clinical and laboratory evidence. *Fundamental and Applied Toxicology*, 3(5), 397-399.
- [15] Medina, D. and Anderson, C.G., 2020. A review of the cyanidation treatment of copper-gold ores and concentrates. *Metals*, 10(7), 897, <https://doi.org/10.3390/met10070897>
- [16] Societe Generale de Surveillance, 2008. *Thiosulphate Leaching - an Alternative to Cyanidation in Gold Processing*. [online]. Available at: <https://www.sgs.com/-/media/global/documents/flyers-and-leaflets/sgs-min-wa018-thiosulphate-leaching-alternative-to-cyanide-in-gold-processing-en-11.pdf>
- [17] Aylmore, M.G. and Muri, D.M. 2001. Thiosulphate leaching of gold - a review. *Minerals Engineering*, 14, 135-174.
- [18] Zhang, H.M. and Senanyake, G., 2016. A review of ammoniacal thiosulfate leaching of gold: An update useful for further research in non-cyanide gold lixivants. *Mineral Processing and Extractive Metallurgy Review*, 37(6), 385-411.
- [19] White, H.A., 1905. The solubility of gold in thiosulfates and thiocyanates. *Journal of the Chemical Metallurgical and Mining Society of South Africa*, 5, 109-111.
- [20] Chen, J., Deng, T., Zhu, G. and Zhao, J., 1996. Leaching and recovery of gold in thiosulfate based system – a research summary at ICM. *Transactions of Indian Institute of Metallurgy*, 49(6), 841-849.
- [21] Ter-Arakelyan, K.A., Bagdasaryan, K.A., Oganyan, A.G., Mkrtchyan, R.T. and Babayan, G.G., 1984. On technological expediency of sodium thiosulphate usage for gold extraction from raw material. *Izv. VUZ Tsvetn. Metallurgy*, 5, 72-76
- [22] Hiskey J.B., 1981. Thiourea as a lixiviant for gold and silver – leaching, recovery and economics. *Proceeding of the 100th AIME Meeting*, Chicago, USA, 22-26 February 1981, 83-91.
- [23] Hancock, R.D., Finkelstein, N.P. and Evers, A., 1974. Linear free energy relationships in aqueous complex formation reactions of the d₁₀ metals ions, *Journal of Inorganic Nuclear Chemistry*, 36(11), 2539-2543.

- [24] Wan, R.Y. and Brierley, J.A., 1997. Thiosulfate leaching following bio-oxidation pretreatment for gold recovery from refractory carbonaceous-sulfidic ore. *Mining Engineering*, 49(8), 76-80.
- [25] Navarro, P., Vargas, C., Villarroel, A. and Alguacil, F.J., 2002. On the use of ammoniacal/ammonium thiosulphate for gold extraction from a concentrate. *Hydrometallurgy*, 65(1), 37-42.
- [26] American Society for Testing and Materials, 2005. *Standard Test Method for Fire Assay Determination of Gold in Copper Concentrates by Gravimetry: Annual book of ASTM E 1805-02*, West Conshohocken: ASTM International.
- [27] Australian Standard, 1991. *Methods for the Analysis of Copper, Lead, Zinc, Gold and Silver Ores: Part 1 Determination of Gold (Fire Assay-Flame AAS Method)*, NSW: Standards Australia.
- [28] Arslan, F. and Sayiner, B., 2007. Extraction of gold and silver from Turkish gold ore by ammoniacal thiosulphate leaching. *Mineral Processing and Extractive Metallurgy Review*, 29(1), 68-82.
- [29] Abbruzzese, C., Fornari, P., Massidda, R., Veglio, F. and Ubaldini, S., 1995. Thiosulphate leaching for gold hydrometallurgy. *Hydrometallurgy*, 39(1-3), 265-276.
- [30] Rath, R.K., Hiroyoshi, N., Tsunekawa, M. and Hirajima, T., 2003. Ammoniacal thiosulphate leaching of gold ore. *The European Journal of Mineral Processing and Environmental Protection*, 3(3), 344-352.
- [31] Hung, H.V., Hai, H.T., Nga, N.T., Lee, J.-C. and Jeong, J., 2011. Study on effect of temperature on gold leaching from electronic scraps using thiosulphate with copper(II) catalyst in ammonia media. *Journal of Science & Technology*, 82A, 37-41.