

## Thiosulfate Leaching In Carbonaceous Gold-Bearing Ores Kaleb Jia Chaka, Unity University

### Abstract

*Gold leaching in metallurgical process is one of the major unit operations in processing plant designs. Conventional cyanidation method had been adopted and is being used widely. However, alternative lixivants over cyanide are being sought by the mining industries. Environmental impacts by cyanide have posed a problem to human life and other biotic species. Research to replace this chemical is being conducted. At this point in time, thiosulfate is claimed to be a better alternative to cyanide.*

*This study presents the performance of thiosulfate as a leaching agent over cyanide in carbonaceous gold-bearing ores. The technical, environmental and economic aspects of using thiosulfate over cyanide have been investigated. A laboratory experiment was conducted to see the leaching effect of both lixivants on carbonaceous gold-bearing ores taken from Legadembu Open Pit Mine. And it was found that thiosulfate has a better and faster recovery of 91.54% over 61.70% of cyanide recovery in 48 hours of leaching time. Graphs and tables are presented to show the technical superiority of thiosulfate over cyanide.*

*Therefore, this work gives indications for the amenability of thiosulfate leaching on carbonaceous gold-bearing ores. A further research perspective is sought for thiosulfate leaching in other refractory ores as well.*

**Key words:** Gold leaching, Carbonaceous, Gold-Bearing Ores

### 1. Introduction

#### 1.1. Research Background

Over the past twenty years, there has been an increase in research into alternative lixivants such as the halogens (Iodine, Bromine, and Chlorine), ammonia, thiocyanate, thiourea, thiosulfate, polysulfides, sulfite, and diethylamine for the treatment of problematic ores (Sparrow and Woodcock, 1995). Increased environmental pressure to ban (or limit) the use of cyanide in plants throughout the world is a prime motivator for research into alternatives to cyanide. Some of these alternatives not only offer a safer and environmentally sound method of extraction but, for some ores, the use of these lixivants can also increase the recovery of gold (Block-Bolten and Torma, 1986; Yen, et al., 1998). With the exception of chlorine, little commercial use has been made of alternative lixivants but several have been tested to pilot-scale plants. The most favored current alternative to cyanide for the treatment of problematic ores is thiosulfate (Abbruzzese, et al., 1995; Michel and Frenay, 1999).

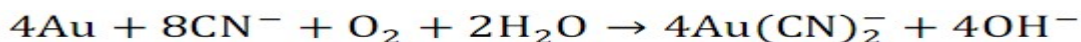
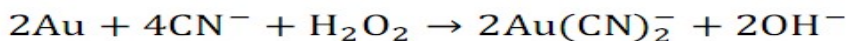
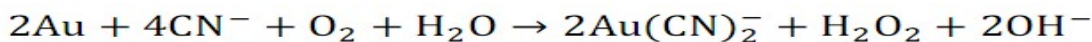
Prior to these lixivants, highly toxic sodium cyanide (NaCN) was used by the international mining community to extract gold and other precious metals through milling of high-grade ores and heap leaching of low-grade ores (Korte et al. 2000). The process to concentrate gold using cyanide was developed in Scotland in 1887 and was used almost immediately in the Witwatersrand gold fields of the Republic of South Africa. Heap leaching with cyanide was proposed by the U.S. Bureau of Mines in 1969 as a means of extracting gold from low-grade ores. The gold industry adopted the technique in the 1970s, soon making heap leaching the dominant technology in gold extraction (Da Rosa and Lyon 1997).

The process of gold dissolution in cyanide (and consequently the extraction of gold from its ores by cyanide) involves heterogeneous reactions at the solid-liquid interfaces. Hence, the

following sequential steps may be assumed as leading to the dissolution of gold (from its ores) by cyanide:

- Absorption of oxygen in solution,
- Transport of dissolved cyanide and oxygen to the solid-liquid interface,
- Adsorption of the reactants ( $\text{CN}^-$  and  $\text{O}_2$ ) on the solid surface,
- Electrochemical reaction,
- Adsorption of the soluble gold-cyanide complexes and other reaction products from the solid surface,
- Transport of the adsorbed products into the bulk of solutions.

The dissolution of gold is an oxidation-reduction process in which cyanide ion forms a strong complex with  $\text{Au}^+$  ion. The stable complex ion is  $[\text{Au}(\text{CN})_2]^-$ . The overall reaction, where oxygen is reduced and hydrogen peroxide is formed to be the oxidizing agent in the second step, is presented below:



However, in recent year's thiosulfate has been considered the most attractive alternative to cyanide for leaching gold, with many investigations taking place around the world. This is primarily based on its low toxicity and its potential use on 'preg-robbing' carbonaceous ores that cannot be readily treated by conventional cyanidation. It has been known for over a hundred years that gold can be leached with thiosulfate. Thiosulfate was the main competitor to cyanide in the 1880's when there was an increase in research to improve gold leaching and recovery from the existing gravity and mercury amalgamation processes.

## 1.2. Objective

This research attempted to present the merits and demerits of using thiosulfate lixivants over cyanide leaching in relation to technical viability, environment and economics.

The research has aimed to study the economic and environmental aspects of using thiosulfate for gold leaching in carbonaceous (preg-robbing) gold-bearing ores. The technical viability has been shown in relation to a better leaching recovery or efficiency over conventional cyanidation method. Thus, it will be useful in shading new light on the problem or in filling the gap in the knowledge pertaining to the given area; as there are few articles released in relation to the proposed subject under study. The researcher believes this paper will give an insight to the reader as to applicability and environmental and economic aspects of using thiosulfate lixiviant over cyanide leaching.

The result of this research will have peculiar significance to Ethiopia's Gold metallurgical context in addition to research conducted on thiosulfate leaching by other researchers.

## 2. Research Methodology

Initially, a thorough investigation was carried out to study the nature of carbonaceous ores and their limitation to conventional cyanidation process. For this purpose, a number of

articles, books and research papers were reviewed. Then the application and technical viability of thiosulfate as leaching agent was studied. The impacts of associated reagents used in leaching have also been researched. The researcher, to that effect, has tried to substantiate his research by conducting laboratory tests for the leaching process. This has helped to establish the effect of some of the parameters under study. These are discussed in detail in Chapter 2 and Chapter 5 of this paper.

Next, environmental impacts of cyanidation process are studied to magnify the non-environmental effect of thiosulfate leaching. Needless to say, the research paper has tried to show how this chemical (CN<sup>-</sup>) is of environmental concern to bio-species and why a ban is sought in its use in the mining industry.

Finally, the economics of employing thiosulfate leaching over conventional cyanidation method for carbonaceous gold-bearing ores has been dealt with. This is followed with a conclusion and recommendation along with the result of the technical investigation conducted. The research was conducted with the schedule shown in table 1.1 below.

### **2.1. Experimental Method**

A small-scale laboratory test was conducted by the researcher to check the amenability of carbonaceous gold-bearing ores on thiosulfate leaching. The test aims to show the technical advantage of using thiosulfate leaching over conventional cyanidation method for such gold-bearing ores.

This was conducted with initial conditions obtained from the literature review on optimum leaching conditions for thiosulfate lixiviant; and experience from Midroc Gold Mine at Legadembi has been adopted for cyanidation optimum conditions. The laboratory experiments and the results obtained from the test are presented as follows.

### **2.2. Origin of the Ore Sample**

A muck ore sample (broken ore) from the Legadembi Open pit Gold mine was obtained for test from two locations customarily known by the geologists at site as Footwall on the North-East side which is believed to contain carbonaceous ores with grades greater than 1g/ton of gold. The samples' location in global coordinates is as follows:

- **Sample-1:** 5749.8m N, 5536.5m E and 1940m Elev.
- **Sample-2:** 5736.8m N, 5529.9m E and 1940m Elev.

The cumulative weight of the samples is around 30Kg with crushed ore size not more than 10cm.

The Legadembi Open pit mine is owned by MIDROC Gold Mine plc. This is the only mechanized large scale gold mining company in Ethiopia and it is located to the extreme southern part of Ethiopia in Oromia region nearby Shakiso town. The ore deposit is mainly a vein type Quartz-Mica-Schist (QMS) with the presence of sulfide minerals as indicators for the presence of gold. Refractory ores of carbonaceous type which are of interest to this research paper have a limited occurrence in the Mine though; their input to the gold production process can't be undermined.

### **2.3. Sample Preparation**

The Legadembi Open pit sample was oven dried for over 20 hours to evaporate surface moisture of the ore then ground to P80 (80% passing) of 75 µm in pulverizer for 5 minutes.

Both ore samples were combined in a ratio of 1 to 1 to a representative sample ore. Mixing the two samples in a tumbler for half an hour ensured homogenous distribution of the samples.

## 2.4. Leaching Experiment

Prior to the leaching test, a sample of the ore was sent to the Analytic laboratory for gold analysis by fire assay; and it was found through triplet sample analysis that the ore sample contains 1.25g/ton of average gold grade. A series of bottle leach tests were carried out on the combined ore sample to determine the concentration of reagents required to achieve the maximum gold extraction. Concentrations of the various reagents used in the test are given below. All reagents were dissolved in a beaker and the pH adjusted to greater than 10.5 and 11.5 using quick lime (CaO). A pH meter was used to measure the pH of the solution. Test 1 and 2 were the base case and were run in parallel while Tests 3 and 4 had one parameter changed from the base case and were run in parallel. The following summary briefly depicts the tests conducted and the parameters analyzed for this research purpose.

**Table 1.1: Sample Gold Assay Triplet Analysis**

Sample No.	Grade (gm/ton)	Average Grade (gm/ton)
Sample No. 1	1.34	
Sample No. 2	1.19	<b>1.25</b>
Sample No. 3	1.22	

### Laboratory Test Summary

**Activity:** Thiosulfate leaching Vs. Cyanide leaching in Carbonaceous Gold Bearing Ores

**Duration:** April 12<sup>th</sup> - 22<sup>nd</sup> 2016.

**Venue:** MIDROC Gold Mine Metallurgy and Legadembi and Sakaro Laboratory Services.

#### I. Laboratory Test Conditions:

- Keep the pulp density constant at 50% solid (pulp density) and vary the concentration of the lixivants.
- Keep the pH range 10.5-11.5.
- Keep the leaching process going for 48hrs residence time (or leaching time).

General test conditions which are common for the tests for comparison purpose such as % solid, pH, residence, time, etc., were kept constant to be used as ground for comparing the two leaching agents. The initial solution strength will vary; and focus will be on the free cyanide in solution to see the preg-robbing effect and to make up for the lost cyanide for assisting the leach.

#### Procedure:

1. Take sample and crush it to a size of -10mm with a jaw crusher.
2. Take the crushed sample and crush it again to a size of -1mm with a Boyd crusher (for 5mins).
3. Then pulverize (grind) the crushed material to a size of -75microns to liberate the metal (Au) inside the ore.
4. Then with a manual splitter, obtain a representative sample of size 2Kg for the tests (four samples).

5. Prepare the reagents to be added with the appropriate concentration strength.
6. Prepare a 50% solid sample by adding 2 lit of water to the prepared 2Kg samples.
7. Adjust the pH of the pulp to come to above 10.5 and 11.5 by adding lime (CaO) accordingly.
8. Finally, add the reagents to their respective leach bottles into the prepared pulp and start agitating the mix to 200rpm to promote homogeneity and increase the kinetics of the reaction thereby increasing the leaching process.
9. Take leaching samples to check the progress of dissolution of gold with the proposed lixivants.

### **First Run**

1. Head grade	1.25 g/t
2. NaCN strength	0.5 g/l
3. TS strength	9 g/l
4. Ammonia	13.6 g/l
5. Copper Sulfate	0.8 g/l
Sample size	2kg
Pulp Density	50 % solid
pH Range	10.5
Residence Time	48 hours
Temperature	Room temperature (20-25 °C)

### **Second Run**

1. Head grade	1.25 g/t
2. NaCN strength	0.25 g/l
3. TS strength	8 g/l
4. Ammonia	13.6 g/l
5. Copper Sulfate	0.8 g/l
Sample size	2kg
Pulp Density	50 % solid
pH Range	11.5
Residence Time	48 hours
Temperature	Room temperature (20-25 °C)

## **Laboratory Apparatus and Instruments**

The following apparatus and instruments were used by the researcher with the help of the laboratory technician in due process of conducting the leaching experiment at MIDROC Gold Mine Laboratory Services. The instruments and their model are provided below.

- Rolling bottles: for undertaking the leaching experiment.
- Flask: for preparing reagents.
- Test tube: for taking periodic solution samples from rolling bottles.
- A Spectroscopy (Atomic Absorption Spectroscopy): for determining gold concentration in solution (GBC SAVANTAA series).
- Jaw crusher: for primary crushing (CHRISTY KUNT EARLS LOLNE).
- Boyd crusher: for secondary crushing (ROCKLABS MK 111).
- Standard Ring mill (Pulverizer): for grinding/milling/ to finer size (ROCKLABS C. PB.).
- Bottle roll machine: for agitating leach solution.
- Beaker: for direct taking samples for pH measurement.
- Filter Press, pulp sample: for filtering solid residue.
- Drying Oven: for removing moisture (HEDINAIN).
- Chemical mixer: for homogenizing/mixing/ samples thoroughly (TURBULA).
- Technical Balance: for measuring weight (SARTORIUS MC 1).
- Cupellation furnace: for heating lead couples at 950 °c to obtain prills (EMF-C).
- Fusion furnace: for fusing electrum with fluxing chemicals at 1100°C (EMF-E).
- Hot Plate: for heating the reaction of electrum with Aquaregia at 130 °C (ROBAX TYPE 445R).
- Mercy Scale: for measuring pulp density.



**Fig. 2.1: Atomic Absorption Spectroscopy machine (AAS)**

## 2.5. Challenges Related to the Laboratory Activity

Laboratory tests ought to be conducted in a very controlled environment, where the researcher could have a qualitative and quantitative control over every parameter to be used in conducting the test. The following two major challenges have been faced by the researcher which may affect the result of the leach.

In gold leaching tests, pressurized air is supposed to be supplied with a specified flow rate in a pipe to promote kinetics of the reaction. However, the researcher couldn't manage to have such fittings to entrain oxygen into the leach system.

Sulfites are thought to make up for the disproportionate thiosulfate in the leach system. The researcher couldn't find sulfite in Legadembi chemical store for his test. However, the pH is kept as alkaline media as much as possible to avoid the loss of unutilized thiosulfate from the system since the disproportionate reaction prefers to occur in acidic media.

## 3. Result and Discussion

While the detail chemistry of thiosulfate leaching of gold is still under investigation by many scholars, this research has tried to make laboratory tests to show results of technical superiority of thiosulfate over cyanide. The results for the two test runs are depicted on the tables below showing their differences in general leach conditions as mentioned in chapter 3 of this paper.

Economic aspect of leaching by comparing thiosulfate lixivants vs. cyanide chemical has been presented to show results in economic terms and help reach on sound conclusion.

### 3.1. First Run

**Table 3.1: First Run Laboratory Result**

<u>Test-1</u>	<u>Thiosulfate (9Kg/ton)</u>			
Time (hr.)	Au in solution (gm/ton)	%Recovery (%)	pH	
0	0.00	0.00	10.50	
2	0.32	25.64	11.18	
4	0.40	32.05	10.90	
8	0.52	41.67	10.62	
24	0.71	56.89	10.07	
30	0.74	59.29	9.79	
48	1.13	90.54	10.24	
<u>Test-2</u>	<u>Sodium Cyanide (0.5Kg/ton)</u>			
Time (hr.)	Au in solution (gm/ton)	%Recovery (%)	pH	Free CN <sup>-</sup> (ppm)
0	0.00	0.00	10.50	500
2	0.26	20.83	10.26	460
4	0.35	28.04	10.24	450
8	0.51	40.87	9.97	350
24	0.63	50.48	9.86	300
30	0.72	57.69	10.65	285
48	0.77	61.70	10.24	200

Similar test conditions have been used for both leaching agents above. So, as it is clearly depicted on the table, thiosulfate shows higher technical superiority over cyanide by achieving about **90.54%** gold recovery in solution over that of **61.70%** for cyanide in 48hrs of residence time. This implies that thiosulfate has quite better leaching recovery than cyanide in carbonaceous preg-robbing gold bearing ores.

### 3.2. Second Run:

**Table 3.2: Second Run Laboratory Result**

<u>Test-3</u>		<u>Thiosulfate (8Kg/ton)</u>		
Time (hr.)	Au in solution (gm/ton)	%Recovery (%)	pH	
0	0.00	0.00	11.50	
2	0.41	32.85	11.67	
4	0.46	36.86	11.61	
8	0.52	41.67	11.44	
24	0.74	59.29	11.59	
30	0.78	62.50	11.51	
48	0.83	66.51	11.18	
<u>Test-4</u>		<u>Sodium Cyanide (0.25Kg/ton)</u>		
Time (hr.)	Au in solution (gm/ton)	%Recovery (%)	pH	Free CN <sup>-</sup> (ppm)
0	0.00	0.00	11.92	250
2	0.22	17.63	11.69	150
4	0.30	24.04	11.60	35+150
8	0.37	29.65	11.42	150
24	0.33	26.44	11.72	100+150
30	0.45	36.06	11.35	200
48	0.48	38.46	11.21	150

The fourth test's result clearly shows the preg-robbing effect of carbonaceous gold bearing ores as the free cyanide in solution gets lost upon leaching progress. As the cyanide leaching above shows, there is a great loss of free cyanide in solution starting from 4<sup>th</sup> hour when leaching started which shows 35ppm of free cyanide in solution and this is attributed to the nature of the ore which absorbs free cyanide in solution to form other unwanted cyanide complexes. However, it is worthwhile to mention here that a minimum of 100-150ppm of free cyanide should be present in solution for there to be gold dissolution. Therefore, 0.15gm/lit of free cyanide was added to the leach solution at the 4<sup>th</sup> and 24<sup>th</sup> hours to make up for the lost cyanide in solution. This will have a negative cost impact of too much dose of cyanide consumption for carbonaceous gold-bearing ores in turn escalating the processing cost of conventional cyanidation for such ores.

The result also shows a better leaching recovery of **66.51%** of thiosulfate over **26.44%** cyanide leach in 24 hrs of residence time; implying a faster leach recovery by thiosulfate. The figures here only show an indication of technical superiority of thiosulfate over cyanide. But, if conditions could be optimized to a better state with researches to be taken by varying reagent concentrations and other conditions for leach, a much better recovery and sound



figures could be obtained. The lower % recoveries and fluctuations in recovery for cyanide in Test-4 also show preg-robbing effect, whereby the leached gold in solution is robbed by the free carbon and other hydrocarbons from the carbonaceous ore which dictated a significant decrease of gold in solution. The other point which the researcher notices on his test result was the state of the alkalinity of the solution for optimum thiosulfate recovery. Test-1, which was conditioned at pH 10.5, resulted in better recovery of about 90.54%, whereas Test-3 which was conditioned at pH 11.5 resulted in 62.5% of solution recovery. This result clearly shows that a better and fast recovery of gold in thiosulfate solution is obtained at the lower alkaline bound which is about pH of 9 – 10.5. This is the pH where optimum recovery of gold in thiosulfate solution could be achieved. The discussions on the above leaching results could easily be depicted on graph as follows with residence time Vs %recovery.

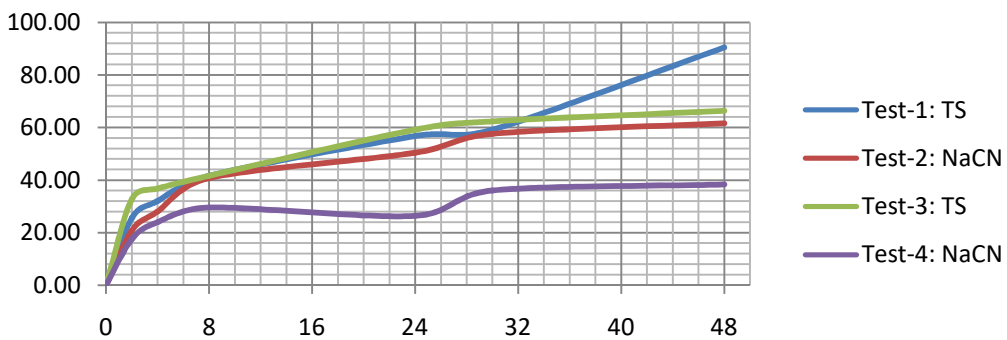


Fig. 3.1: %Recovery Vs Residence Time Graph

Finally, the gold left in the solid as residue after being fire assayed on finishing the leaching process was examined in laboratory and the result is shown in the table 4.3:

**Head grade = 1.25 g/ton**

**Residence Time (hr.)**

**%Recovery %**

**Table 3.3: Gold Grade in Solid Residue**

Test No.	Solid Grade (Residue, g/ton)	Au in Solution after 48hrs. (g/ton)	Head Grade (gm/ton)
Test-1 (TS)	<b>0.12</b>	<b>1.13</b>	
Test-2 (CN)	<b>0.50</b>	<b>0.77</b>	<b>1.25</b>
Test-3 (TS)	<b>0.45</b>	<b>0.78</b>	
Test-4 (CN)	<b>0.68</b>	<b>0.48</b>	

### 3.3. Economic Result of Leaching Experiment

A cost comparison of thiosulfate leaching of gold ores with conventional cyanidation method is presented here. Costs associated with direct chemical consumption are used for both lixivants along with the major operating costs incurred upon detoxifying the cyanide from the tailing management facility on the conventional cyanidation method. The costs and the procedure for analyzing the costs are provided in table 3.5.

The following cost of reagents is obtained from the Legadembi metallurgy facility on current market price basis.

**Table 3.4: Leaching Reagent Consumption and Rost**

Chemical Name	Unit	Unit price (ETB)	Specific Consumption (Kg/ton)	Amount (ETB/ton)
Sodium cyanide	Kg	81.69	0.80	<b>65.35</b>
Sodium thiosulfate	Kg	16.60	9.00	<b>149.40</b>
Ammonia	Kg	9.00	13.60	<b>122.40</b>
Copper sulfate	Kg	44.00	0.80	<b>35.20</b>
Hypochlorite	Kg	79.64	0.02	<b>1.59</b>

Taking a particular case for Legadembi, a facility which processes 1,100,000tons of ore annually, to estimate operating costs; the detox plant for Legadembi Gold Mine uses a minimum of 20 tons of hypochlorite per annum for treating cyanide in tailing solution and taking an average power consumption charge of 0.60ETB/kwt hr by EEPCO. The following table provides information about operating cost analysis for the detoxification of cyanide tailings.

**Table 3.5: Detoxification operating cost analysis**

<b>No.</b>	<b><u>Major Detox Plant Operating Items</u></b>	<b><u>Costs per Annum (ETB)</u></b>
1	Workforce cost (four operators working for 8hrs/day in three shift at monthly salary of 6000ETB each)	288,000.00
2	Electrical spares (breakers, contactors, cables e.t.c...)	200,000.00
3	Mixing tank agitator power consumption (rated capacity of 11kwt working for 24hrs per day)	57,816.00
4	Tank spare costs (gearbox and other spares...)	200,000.00
5	Transfer pump power consumption (rated capacity of 11kwt working for 24hrs per month)	1,900.80
6	Dozing pump power consumption (rated capacity of 10kwt working for 20hrs per day)	43,800.00
7	Pump spare cost	300,000.00
8	Pipes & Valves Operating expense (wear & tear, other replacements)	250,000.00
9	Cyanide titration & PH determination cost (Operating cost for consumables with 150ETB per day)	54,750.00
	<b>Carried to summary:</b>	<b><u>1,396,266.80</u></b>
	<b><u>Tailing Dam Cost (Tailing Transportation Items)</u></b>	
1	Operating cost for consumables (pipe replacement, fittings, spigot pipes e.t.c...)	600,000.00

2	Workforce cost (four attendants working for 8hrs/day in two shifts at monthly salary of 4000ETB each)	192,000.00
	<b>Carried to summary:</b>	<b><u>792,000.00</u></b>
	<b><u>Tailing Water Return Cost Items</u></b>	
1	Return Pump power consumption (Two pumps with rated capacity of 11kw working for 23hrs/day)	110,814.00
2	Electrical spares (breakers, contactors, cables e.t.c...)	100,000.00
3	Pump spare costs (Mechanical fill and others...)	1,200,000.00
4	Bearings cost (six bearings per annum each costing 10,000ETB)	60,000.00
5	Hose and Valves cost	150,000.00
6	Return Pipe and Fittings cost	500,000.00
7	Workforce cost (four operators working for 8hrs/day in three shifts at monthly salary of 4000ETB each)	192,000.00
	<b>Carried to summary:</b>	<b><u>2,312,814.00</u></b>
	Supervisor for the three Units (One person working for 8hrs/day with monthly salary of 10,000ETB)	120,000.00
	<b>Total Sum:</b>	<b><u>4,621,080.80</u></b>
	<b>Annual Budgeted Plant Processing</b>	<b>1.1 million tons</b>
	<b>Unit Cost for Detoxification of Cyanide Tailings (ETB/ton)</b>	<b><u>4.20</u></b>

Pre-treatment of ores is mandatory for refractory ores before leaching with cyanide. Thus, roasting of ores as pre-treatment method has been adopted for this economic analysis. The roasting cost for carbonaceous ores here has been estimated with taking a particular case of Derba cement's clinker production kiln.

- The Derba kiln uses around 735 kcal of energy to produce 1Kg of clinker
- The cement plant mostly uses lignite coals as energy source with caloric value of around 2310 Kcal/Kg
- Lignite coal types are sold with 938.40 ETB per ton at international market including 20% for overhead cost

**Table 3.6: Roasting cost estimation**

Pre-treatment (Roasting cost)		Economic output
Kiln coal requirement	0.32 Kg/Kg of clinker	300.80 ETB/ton of clinker
Lignite unit price	0.94 ETB/Kg	

The cement plant kiln for clinker production could here be taken as equivalent to a kiln used for roasting of refractory ores to produce pre-treated ores for cyanide leaching for estimating roasting cost; which resulted in 300.80 ETB/ton of ore pre-treated. In summary, the above cost analysis gives the following summarized costs for both lixivants as shown in table 4.7:

Therefore, the result from the above analysis shows that thiosulfate leaching of gold takes the advantage in economic terms, too. This economic advantage by thiosulfate could further be exploited to a better level by optimizing the thiosulfate leach process for refractory ores which would likely reduce the use of higher concentration of reagents in the leach system. The higher cost by conventional cyanidation method shows the reason why this method is not used for treating such type of refractory ores. As observed from the test results above, thiosulfate recovery has significant superiority over cyanide, this can be considered as additional revenue and efficient operation with minimum loss of precious minerals with tailings. Moreover, if the none-environmental impacts of thiosulfate as compared to cyanide could be put in monetary terms, this would definitely magnify the economic advantage of thiosulfate leach system for carbonaceous ores.

**Table 3.7: Leaching economics result**

Leaching Method	Total Unit Cost (ETB/ton)
Cyanide Leaching	371.94
Thiosulfate Leaching	307.00

#### 4. Conclusion and Recommendation

In conclusion, this research paper showed a positive result for the initial hypothesis drawn for this research purpose. An initial anticipation of better and faster recovery by thiosulfate was proposed for this research, and that is what the previous sections of this research paper have tried to show. The following points could easily be remarked as sound conclusions for the investigation undertaken here in thiosulfate leaching on carbonaceous gold-bearing ores.

The present study indicated that, thiosulfate with concentration of 9kg/ton has a better recovery of **90.54%** over cyanide of **61.70%** recovery in carbonaceous gold-bearing ores. If further research could be done on the general conditions of the test by varying the critical parameters such as pulp density (% solid), concentration of reagents, pH and so on, this result could be enhanced further to a better level.

The other indication which the result of this research showed is that, a faster dissolution of **66.51%** gold recovery with a minimum residence time of **24hrs** was obtained with thiosulfate. This phenomenon could also be exploited further to a level which is stipulated on some literatures as 73% recovery within 4hrs of residence time provided intensive researches done on parameters affecting the rate of dissolution greatly. From this result, one

can easily foresee the benefits this could have to the leach process by saving costs associated with leach time and number of tanks.

The main chemical components of the leaching process (sodium thiosulphate and ammonia solution) are common fertilizers, which opens up the additional possibility of using mine tailings in agricultural applications, in regions of the world where the local infrastructure and environmental regulations are favorable.

As occurrences of carbonaceous gold-bearing ores are seen in Ethiopia and the depletion of free-milling (non-refractory) ores are evident in the world, this calls attention to the thiosulfate chemicals as an ideal leaching agent for such ore types and their immense use in the near future. The wide application area of this chemical to all refractory ores (sulfides, tellurides, carbonaceous...) offers other definite opportunities for its use.

As environmental concerns are no more luxury items in the 21<sup>st</sup> century and approval for any new gold project using cyanide is extremely unlikely in some areas around the world; thiosulfate becomes the main leaching agent in the near future. Elsewhere, increasing regulatory scrutiny of new gold projects and a lowering of acceptable levels of cyanide discharges are of considerable concern to mining companies. The depletion of free milling ores also pose a pressure to go for thiosulfate leaching as the use of cyanide is not efficient for refractory ore types. These and other related conditions open an extensive ground for the application of thiosulfate lixivants.

A further research perspective was sought by the researcher to increase the amenability of thiosulfate chemicals for gold leaching process. The electrochemistry of the leach process and concepts associated with the reduction potential and Gibbs free energy should be investigated thoroughly given the complexity of the leach chemistry so as to tell the specific conditions where this chemical (thiosulfate) could be of a great use to the mine industry.

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