CAUTION

The following text was prepared to accompany a lecture-discussion which introduces the subject of heap haching gold with cyanide. IT IS NOT COMPLETE WITHOUT THE VERBAL LECTURE-DISCUSSION.

CAUTION

Treatment of ores with cyanide requires use of DEADLY POISONOUS, CAUSTIC AND EXPLOSIVE chemicals. No tests or operations should be undertaken except by experienced or trained individuals.

CAUTION

The text that follows introduces the subject of heap leaching gold with cyanide. Its purpose is to accompany tonight's lecture-discussion. The reader is reminded of the following items:

- 1. This is only a brief introduction.
- 2. It is not a step-by-step procedure.
- 3. Extensive detailed amenability testing by expert laboratories and metallurgists is advised prior to any planned start-up of a cyanide leaching operation.
- 4. Considerable additional information, guidance and suggestions on cyanide leaching is available by visiting the offices of the Department of Mineral Resources and discussing the subject with a department engineer.
- 5. The Department of Mineral Resources and its engineers are not able to provide cyanide or leaching tests or design and supervise operations.

GOLD & SILVER - CYANIDATION Ken A. Phillips Arizona Department of Mineral Resources Introduction

The cyanide process is the most important method ever developed for extracting gold from its ores.

The early development of the process is attributed to a Scotchman, John Stewart MacArthur, in collaboration with the Forrest brothers. The method was introduced into South Africa in 1890. From there it spread to Australia, Mexico and the United States. Not it is used in practically all the major gold mining camps of the world.

The reasons for its widespread acceptance are economic as well as metallurgical. When used in heap leaching the processing and equipment is less

complex and less expensive than other methods. In a milling operation it usually obtains a higher recovery of gold than plate amalgamation and is easier to operate than the chlorine or bromine process. It produces the final product in the form of practically pure metal. Thus the production from a large cyanide mill will be represented by a comparatively small gold bar, which is easy to transport.

The mine owner or operator who is considering the use of cyanide extraction methods MUST have metallurgical and chemical expertise. At the absolute minimum a very good knowledge of high school algebra and chemistry is required.

General Theory

Before going into the theory of the cyanide process, a brief review of the chemical properties of gold may be beneficial.

Gold does not oxide (tarnish) at ordinary temperatures nor is it soluble in sulphuric, nitric or hydrochloric acids. It does dissolve in aqua regia (a mixture of nitric and hydrochloric acid) also in some chlorine and bromine compounds. Gold is soluble in mercury, uniting with it to form amalgam. However, the main chemical property of commercial interest is that gold is soluble in dilute cyanide solutions.

The basis of the cyanide process is that weak solutions of sodium or potassium cyanide have a preferential dissolving action on small particles of metallic gold and silver over other materials usually found in gold ores. However, there are a few minerals known as cyanicides that have deleterious effects which are discussed later.

Cyanide is the general descriptive term applied usually to sodium cyanide, NaCN. The early work in cyanidation was based on the use of potassium cyanide. It is to be noted that the cyanogen radical (CN) actually has the dissolving power, the alkaline base of potassium, calcium, or sodium merely giving a chemical stability to the compound.

Chemistry of Cyanidation

The basic principle of the cyanidation process is that weak alkaline cyanide solutions have a preferential dissolving action on the gold and silver contained in an ore. The reaction (Elsner's equation) generally accepted for several decades as representing the dissolution of gold by cyanide solution is

4Au+8NaCN+0 + 2H 0-4NaAu(CN) + 4NaOH.

The gold dissolution rate is dependent on the concentration of NaCN and the alkalinity of the solution, the optimum pH being 10.3. For efficient leaching, the gold should occur as free, fine-size, clean particles in an ore that contains no "cyanicides" or impurities that might destroy cyanide or otherwise inhibit the dissolution reaction. An adequate supply of dissolved oxygen must be present in the cyanide solution throughout the reaction period.

The chemistry involved in the dissolution of gold in the heap-leach cyanidation treatment is the same as that for the agitation-cyanidation process. In heap leaching, the oxygem, essential for the dissolution of gold, is introduced into the cyanide solution as it is being sprinkled upon the ore heap. The adsorbed oxygen and carbon dioxide from the air may also cause chemical losses of cyanide.

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In heap leaching highly oxidized ores, such as old mine dumps, the decomposition of cyanide by carbon dioxide may be as great as that caused by the acid constituents of the ore. The decomposition of cyanide by carbon dioxide, as well as by ground acids, is minimized by using sufficient alkali such as lime (CaO) or caustic soda (Na)H) in the leach solution to maintain the alkalinity at a pH range of 9 to 11.

The mineral constituents of the ore and other foreign substances can influence the cyanidation process in a number of different ways. Silver normally occurs with gold either as an impurity in the particles of native gold or as silver-bearing minerals. The occurrence of silver in gold ores may range from less than 1 ppm to several hundred times the level of the gold present in an ore. Generally, silver is also dissolved by the cyanide solution and follows the gold through the process sequence. Iron sulfide minerals, which are common constituents of gold ores, are oxidized to some extent during the cyanide leach, thus resulting in the formation of acid. These acids are neutralized by the lime used in the cyanide leach sequence. Copper minerals may be dissolved by the cyanide leach solution and thus consume large quantities of NaCN and oxygen. Arsenic-bearing minerals may also interfere with cyanidation. Realgar (As S) and orpiment (As,S,) react rapidly with the cyanide solution and inhibit the dissolution of gold. Arsenopyrite (FeAsS), however, generally oxidizes very slowly in an aerated cyanide solution and has very little adverse effect on the leaching of gold. Stibnite (Sb S) strongly inhibits cyanidation. The presence of base metal ions such as Fe^{2+3} , Fe^{3+4} , Ni^{2+4} , Cu^{2+4} , Zn^{2+4} , and Mn^{2+4} in the cyanide leach solution will retard the cyanidation of gold. Charred mine timbers act as adsorbents for the gold dissolved by cyanide solutions and cause premature precipitation of gold. Organic substances such as decayed wood, oil, grease, and flotation reagents (all of which are often contained in old mill tailings) slow down cyanidation of gold by consuming the dissolved oxygen in the leach solution and also inhibits subsequent gold recovery from leach solution by precipitation of the gold on zinc dust.

Generally, gold and silver are recovered from pregnant cyanide solutions either by precipitation on zinc dust or by adsorption on activated carbon. For precipitation of gold on zinc, clarification (filtering) of the pregnant solution is required to eliminate the suspended clayey constituents that can coat the zinc particles and retard precipitation of the precious metals. Elimination of the dissolved oxygen from the pregnant solution is also essential to prevent the redissolution of the gold and excessive zinc consumption. The precipitation of gold on zinc is greatly improved by adding soluble lead salts,

such as lead acetate or lead nitrate, to cyanide solutions to form a zinc-lead couple of greater activity.

Activated carbon has the capability of adsorbing the gold cyanide complex from cyanidation reaction pulps and unclarified cyanide effluents. Thus, liquid-solids separation, clarification, and deaeration processing steps are eliminated. Although activated carbon has been used in gold-silver recovery from cyanide solutions for several decades, the mechanism of gold adsorption on activated carbon is still not fully understood.

Minerology Of Gold Ores

The manner of gold occurrence and its association with the gangue minerals dictate whether or not the ore can be processed by the cyanide heap-leach method. From a metallurgical standpoint, gold ores may be roughly classified as:

- Simple oxide ores containing fine particles of native gold in quartz or limestone (calcite) gangue (some Arizona gold-quartz veins).
- II. Simple sulfide ores in which the gold is associated with minor amounts of pyrite or arsenopyrite.
- III. Placer or alluvium material.
- IV. Complex or refractory ores in which the gold bearing mineral species are not readily soluble in cyanide solution.
- V. Complex base metal ores in which the precious metals are important economic constituents.
- VI. Base metal ores in which the precious metals are of minor value and are by-products.

Of these, only the simple oxide and sulfide ores and certain placers are suitable for leaching. Further, these materials must possess all of the following characteristics:

- A. Gold and silver values are leachable by cyanide solutions.
- B. The size of the gold particles is extremely small.
- C. The host rock is porous to cyanide solution and remains so during the relatively long leach cycle; or D. below:
- D. Gold particles in ores of low porosity are liberated or exposed by fracturing and crushing.
- E. The ore is free of carbonaceous material which has the capability of adsorbing gold cyanide and causes premature precipitation of the gold.
- F. The ore is relatively free of "cyanicides" or substances that destroy cyanide or interfere with the gold-cyanidation reaction, such as partially oxidized sulfides of antimony, zinc, copper, and arsenic containing minerals.
- G. The ore does not contain excessive amounts of "fines" or clayey constituents that will impede solution percolation.

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H. The ore is relatively free of acid-forming constituents that cause high lime consumption.

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The types of gold-bearing deposits found amenable to heap leaching are as follows:

- 1. Vein quartz ore in which gold occurs in limonite rich cavities and fractures. These occur in many districts in Arizona.
- Igneous host material cut with small quartz veins (stringers) containing free gold and minor amounts of pyrite. These occasionally occur in Arizona.
- 3. Schist containing free gold in the lamination of the rock. These may occur in Arizona.
- 4. Siliceous quartz sinter of hot-spring origin which contains gold. A slight possibility exists for future discovery of these in Arizona.
- 5. The following three types of gold-bearing deposits which are also amenable to cyanide leaching are not now known to exist in Arizona.
 - a. Limey siltstone containing submicrometer-size gold particles and minute amounts of pyrite, galena, cinnabar, and stibnite.
 - b. Silicified siltstones containing micrometer-size particles of gold, often associated with residual iron oxides.
 - c. Sanded dolomite ore in which fine gold particles occur on the intergranular surfaces.

The Heap Leaching Process

The heap laching process, as shown in the flowsheet, figure 1, consists of piling coarse, treatable ore on an impervious pad and percolating it with small amounts of dilute lime-cyanide solution. Unclarified gold-bearing solution draining from the heap is passed through the U.S. Bureau of Mines designed expanded-bed, multiple-compartment activated-carbon column to recover nearly all of the gold and is then returned to the leaching step. Loaded carbon is stripped of its gold content in a new Bureau-developed pressure system, reactivated, and returned to the column. Gold is electrowon from the stripping solution. Gold may also be recoverable from the leach solution by the clarification, deaeration, zinc precipitation method.

To be treatable by heap leaching, gold-bearing rock should be competent, porous, relatively cyanicide-free, and contain fine-sized clean gold particles. Clay content must be low enough that the ore heap remains permeable to percolating solutions during leaching.

In commercial application, the leaching pads have been made of asphalt, protected vinal or other impervious material, or earth lined with clay as at some copper-leaching operations. Ore sizes have ranged from mine run to about 1/2 inch, depending upon solution penetrability of the rock. The depth of the heap has been 6 to 20 feet or more. Solution strengths have ranged from 0.02 to 0.1 percent NaCN, depending on ore requirements, and the pH has been main-tained at about 10.5 with lime. The rate of solution application by sprays

has ranged from 5 to 25 gallons per square foot per 24 hours. Adequate storage has been provided for pregnant solution between the leaching heap and the gold recovery step that follows.

A three stage countercurrent column using minus 10- plus 20-mesh activated carbon for gold recovery from the leach liquor would be expected to produce a 0.0002-ounce barren solution from 0.04- to 0.20- ounce pregnant solution and to load the carbon to about 400 ounces per ton, while flowing at the rate of 15 to 20 gallons per minute per square foot of column cross-section. From the ecological standpoint, heap leaching has a low potential for pollution. The residues are coarse and nearly dust-free, no gases are emitted, and all solutions are recycled.

Heap leaching results based on laboratory and pilot tests of amenable ores are given in Table 1. Gold recoveries of 67 to 95 percent were obtained with consumption of 0.4 to 1.0 pound NaCN per ton of ore and 0.3 to 5.6 pounds of lime. Gold recoveries in successful heap leaching operations are ranging from 40% to 80%. Leaching time varied roughly with the rock size from 4 days at 1/2-inch to 42 days at 4-inch size. However, individual ore amenability may be a more important factor in leaching response than rock size.

Sample	Ore size, inches	Gold assay, <u>oz/ton</u> Head Tail		Gold recovery, pct	Leaching time days	Reage consump <u>lb/ton</u> NaCN	Reagent consumption, <u>lb/ton ore</u> NaCN CaO	
1	1/2	0.63	0.03	95	4	0 7	27	
2	1	.022	.002	91	6	5	2.7	
3	1	.068	.015	86	6	.4	.5	
4	1-1/4	. 08	.02	76	21	.7	3.5	
5	2	.20	.03	84	36	1.0	4.3	
6	2	.09	.03	67	23	1.0	5.6	
7	4	. 25	.04	83	42	1.0	4.9	

TABLE 1. - <u>Results of percolation leaching of gold ores</u> <u>and stripping waste</u>



FIGURE I.- Gold Heap Leaching.

from U.S. Bureau of Mines

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