AN INVESTIGATION OF THE
CYANIDATION OF A GOLD ORE

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A THESIS

SUBMITTED TO

THE BOARD OF TRUSTEES, PRESIDENT,

AND FACULTY

OF

THE COLORADO SCHOOL OF MINES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR

THE DEGREE OF

MASTER, ENGINEER OF METALLURGY

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GOLDEN, COLORADO

MAY 5, 1948

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INTRODUCTION

While assisting in the instruction of a class in hydrometallurgy given by the Department of Metallurgy at the Experimental Plant of the Colorado School of Mines, I observed a very interesting but complex gold ore. A subsequent course in advanced hydrometallurgy provided the incentive to study this ore more thoroughly and eventually led to the investigation of this problem.

The ore comes from a mine at La Paz, Mexico, in the lower peninsula of California. It is a representative sample of hundreds of tons of ore from the sulfide zone of the mine that have been broken and left standing in the stopes for numerous years. The ore is a very heavy sulfide, and necessarily has been somewhat oxidized because of the long period during which it has lain in the stopes since being broken.

Analysis of the ore shows it to contain considerable amounts of arsenic as arsenopyrite, lead as galena, and iron as pyrite, as well as amounts of zinc, antimony, and copper. It contains from three to four ounces of gold per ton and approximately twelve ounces of silver per ton.

The company operating the mine has not attempted treatment of this sulfide ore. Although it is presently treating ore from the oxidized zone of the mine, the extraction of gold from the ore in the oxidized zone is not satisfactory. The company realizes the difficulties to be encountered in treating this type of ore. It contains arsenic, which is known to be refractory to direct cyanidation. Cyanidation of gold ores containing arsenic is a subject concerning which little is known and about which little information is available.

This thesis is the record of an investigation undertaken in an effort to determine a commercial method of extracting the gold from this ore. Because roasting is prohibitively expensive for such a company, this investigation has dealt only with cyaniding the ore directly. The purpose has been to determine methods of improving the extraction of gold from this ore and reasons why this type of ore is refractory to cyanidation. The author feels that oxygen, or perhaps the lack of oxygen, is important in the cyaniding of this ore; therefore the role of oxygen has been investigated extensively. Others have said that arsenic precludes the re-use of barren solutions; this too has been investigated. If re-use were impossible, the arsenic would necessarily form some fouling compound, about which, to date, no conclusions have been made. A satisfactory method for the extraction of gold from this ore may conceivably aid in the extraction of gold from other similar ores.

Acknowledgement is due to Professor Clark B. Carpenter of the Department of Metallurgy for general aid and guidance throughout this work, and to A. L. Pierce, Chemist for the Department of Metallurgy, for general aid and assistance in the chemical aspects of this problem.

THE CYANIDE PROCESS

The Cyanide Process has for its object the commercially profitable recovery of gold and silver from their ores, which is accomplished by the solvent action of an alkaline cyanide solution on the precious metals.

This process owes its origin to three men: J. S. MacArthur, a metallurgical chemist, and R. W. Forrest and W. Forrest, doctors of medicine, all of Glasgow, Scotland. In England on October 19, 1887, they registered their first patent, covering the use of potassium cyanide as a solvent in weak solutions. The following year they registered patents on the use of alkalies, on methods of applying cyanide, and on the use of zinc for precipitation. The original claims of these men are remarkable in that very little of their original work has been disproved in present-day practice. Although these men are given much of the credit for the origin of the Cyanide Process, a German chemist, L. Elsner, published findings of his experiments in 1846, which included the basic idea of cyaniding. Yet, as do many others, he failed to realize the practical aspects of his investigations and nothing was done with his findings until MacArthur and the Forrests obtained their patents 1/.

1/ Dorr, John V. N., Cyanidation and Concentration of Gold and Silver Ores, McGraw-Hill Book Company, first edition, 1936, pp. 1-2.

The solvent, in addition to containing cyanide, should contain free alkali, to provide protective alkalinity that prevents the formation of hydrocyanic acid, the formation of which both is hazardous and presents a problem in its loss of available cyanide or cyanide which dissolves gold. Lime is used nearly always to provide this protective alkalinity, and it also is of considerable aid in the clarification of solutions in thickening.

The final step in the Cyanide Process is the metal recovery. The final product obtained here determines whether or not the operation is to be profitable. Metal recovery is accomplished mostly by precipitation of the pregnant solutions with zinc dust or shavings. The precipitate is melted down with the proper fluxes and cast in bullion for sale to the mint.

CHEMISTRY OF CYANIDATION

Dissolution

The usual reaction for the dissolution of gold in alkaline cyanide solution, commonly referred to as "Elsner's Equation," is as follows:

$$2\ Au + 4\ NaCN + \tfrac{1}{2}\ O_2 + H_2O = 2\ NaAu(CN)_2 + 2\ NaOH$$

Clennell 2/ states that Bodlander believes that there may be intermediate products of reaction in this equation, which would make the reaction above not so simple as it appears. He maintains that hydrogen peroxide is first produced, for it or some other substance having similar reaction can be detected in the solution.

$$2\ Au + 4\ NaCN + 2\ H_2O + O_2 = 2\ NaAu(CN)_2 + H_2O_2 + 2\ NaOH$$

Then, when this is further decomposed, an additional amount of gold is dissolved.

$$2\ Au + 4\ NaCN + H_2O_2 = 2\ NaAu(CN)_2 + 2\ NaOH$$

Clennell further states that Bettel believes that the intermediate product is sodium auricyanide.

2/ Clennell, J. F., The Cyanide Handbook, McGraw-Hill Book Company, 1910, p. 102.

(a) $2\ Au + 6\ NaCN + 2\ H_2O + O_2 = NaAu(CN)_4 + 4\ NaOH + NaAu(CN)_2$

(b) $2\ Au + 2\ NaCN + NaAu(CN)_4 = 3\ NaAu(CN)_2$

Dissolution requires the presence of a less basic or less electropositive substance than the gold. This is always taken care of by the occurrence of minerals such as pyrite, in the gold ores. This fact may be proved by suspending gold metal foil of the highest purity in a solution of chemically pure cyanide. Here, no appreciable action takes place. But if a less basic mineral is added and attached to the gold foil, a rapid initial reaction takes place, with hydrogen being given off at the surface of the less basic mineral 3/.

3/ Julian, H. F., and Smart, Edgar, Cyaniding Gold and Silver Ores, Charles Griffen and Company Ltd., second edition, 1913, p. 70.

From this it is seen that oxygen is necessary in the dissolution of gold, either as a depolarizing agent to remove the hydrogen from the surface of the less basic substance, or as a direct agent, as shown in Elsner's equation.

Electro-chemical Changes

Alkaline cyanide will ionize in solution and form undissociated ions of Na^+, and $(CN)^-$, either in part or in whole according to its dissociation constant.

$$K = \frac{(Na^+)\ ((CN)^-)}{NaCN}$$

The anions, $(CN)^-$, migrate to the anode or the gold and form gold cyanide, (AuCN), which is in turn dissolved by an excess of sodium cyanide to form sodium aurocyanide, $NaAu(CN)_2$. The cations, Na^+, migrate to the cathode, or the less basic substance, and give up their positive charge. The Na atom cannot remain in a free state in the solution, but instantly attacks the water and liberates hydrogen ions, H^+, and forms potassium hydroxide 4/.

4/ Idem.

Factors That Influence Solubility of Gold

There are many factors influencing the solubility of gold in alkaline cyanide solutions:

1. Degree of concentration of the solution: The reduced efficiency of strong solutions has been ascribed to the diminished solubility of oxygen in strong alkaline cyanide 5/. Available cyanide is essential for the dissolution of gold and is obtained by the dissociation of cyanide into its ions, Na^+ and $(CN)^-$. The more dilute the solution, the greater is the dissociation and more $(CN)^-$ available to dissolve the precious metals.

2. Temperature: The rate of dissolution of gold in cyanide solution increases with the rise in temperature. Julian and Smart 6/ found that the rate of dissolution increased to a maximum at 85 C and then slightly decreased to the boiling point.

3. Presence or absence of cyanicides: Cyanicides are base metals that react with the cyanide to form insoluble compounds and thus cause losses of cyanide.

4. Amount of available oxygen: This will be discussed further in the paper.

5/ Clennell, op. cit., p. 105.

6/ Op. cit., p. 91.

5. Physical condition of the surfaces of metallic gold in contact with the solution: When the surface is tarnished, the solubility of the gold is decreased.

6. Area of metal exposed in proportion to weight: The greater the area exposed, the greater the weight of gold dissolved.

7. Presence or absence of reducing agents: These are substances which have the property of denuding the solution of its dissolved oxygen. They may retard or completely stop the action of cyanide.

METHODS OF TREATMENT OF SIMILAR ORES

Preliminary Treatment

Acid Treatment: By treating some ores that have been partly oxidized with a dilute solution of sulfuric acid and then by washing this acid from the ore thoroughly, cyanicides may be removed. This method was used at one time at the Butters Plant, Virginia City, on gold ore containing copper carbonate [7]. In here the ore was washed with water having sufficient quantity of lime to neutralize any remaining acidity.

The difficulty to be encountered in this type of treatment is that the acid may not be completely removed and may cause an excessive cyanide loss.

Lime Treatment: Gold ore is sometimes milled in lime, especially when amalgamation is to be used. The lime will neutralize any acid substances or soluble salts of iron that may tend to tarnish the amalgam plates. It will also dissolve any grease that may get into the ore from

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[7] Clennell, op. cit., p. 310.

the crushing and grinding machinery. It aids in settling finely suspended ore particles by causing them to come in contact with the plates 8/.

8/ Idem., p. 183.

At the Spring Hill mine in Montana, the gold ore contains considerable amounts of pyrrhotite. A consulting engineer, A. L. Norton, attempted to give the ore a sodium hydroxide wash to dissolve the troublesome compound. This treatment failed because the tremendous heat generated in the agitators decomposed the pyrrhotite and formed cyanicides that consumed more than 80 pounds of cyanide per ton of ore. Tests were made on the re-use of barren solution. By using a fresh solution in each leaching cycle an extraction of 95 to 97 per cent was obtained and only 9 pounds of cyanide per ton of ore consumed, whereas, by using the barren solutions over again in each leaching cycle, the extraction was only 50 per cent.

Treatment of Arsenical Gold Ores

E. M. Hamilton 9/ in his book quotes the opinion of W. B. Blyth,

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9/ Hamilton, E. M., Manual of Cyanidation, McGraw-Hill Book Company, first edition, 1920, pp. 162-163.

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who maintains that arsenic in gold ore does not necessarily cause the ore to be refractory to cyanidation. Blyth thinks that when arsenic is present in a gold ore it is nearly always associated with antimony and pyrrhotite. These, if in sufficient quantity, will cause premature precipitation of the gold almost as fast as it goes into solution.

Blyth illustrated the fact that by milling an antimonial gold ore in water and running the pulp into a dam, where it was settled, dried, and allowed to oxidize with an occasional cultivation, the extraction of gold from this ore was improved from 50 to 93 per cent. A similar result was accomplished with the sands by milling the pulp without lime. He claims that because of the solubility of antimony in alkaline cyanide it is not possible to add lime to the mills and achieve good results. Consequently the abraded iron which mainly goes with the slime is reduced to the ferrous state and, independently of the antimony, effectually upsets the extraction from this product when treated directly without lime. In leaching sands, however, it is found that the residue rises proportionately to the lime used, and that the best results are obtained when no lime at all is used. About 1/2 pound of lead nitrate is used per ton of ore and the sand is slimed in an acid solution. The consumption of cyanide is naturally heavy, but the good extraction counterbalances losses in this direction.

Hamilton cites the example of a Mexican arsenical gold ore that was milled in a solution showing no protective alkali. The extraction of gold from the ore was raised to 88 per cent from 68 per cent when milled with protective alkalinity.

When making tests on the cyaniding of Nipissing ore 10/, it was found that arsenic and antimony dissolved out of the ore by the cyanide formed a harmful combination with the zinc derived from zinc precipitation and so caused a serious loss of dissolving power in the stock solutions. It is claimed that zinc in the presence of arsenic and antimony lowers the extraction of silver as much as 10 per cent and the extraction of gold to a lesser degree 11/. Though zinc has this effect, lead

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10/ Hamilton, op. cit., p. 190.

11/ Idem., p. 8.

in solution will often act similarly, and the addition of lead salts may have to be avoided.

The Montana Mines Corporation near Helena, Montana [12], mines an ore in which the gold is associated with pyrite, arsenopyrite, and bismuth. Cyanidation was not a success; however, the innovation of flotation in the mill proved successful.

The Pioneer Mill in the Lillooet district of British Columbia is treating a gold ore carrying small amounts of pyrite, arsenopyrite, and pyrrhotite. The pregnant solution is kept above 60 F during precipitation; other than this, the method of cyanidation is conventional. In 1936 the mill reached a recovery of 97 per cent [13].

At the mine of the St. John del Rey Mining Company Ltd., at Morro Velho in Brazil, the minerals present in crystalline form are pyrite and arsenopyrite [14]. The gold is associated with the arsenopyrite. However, the pyrrhotite that is present is the metallurgical difficulty. Pyrrhotite with the general formula $Fe_mS_m + 1$, has one sulfur atom held loosely in chemical composition. It is easily capable of forming additive compounds, such as sodium thiocyanate, NaCNS, from cyanide. By oxidizing, pyrrhotite yields elemental sulfur and ferrous sulfide, FeS. The ferrous sulfide forms ferrous and ferric sulfate, which are cyanicides. These reactions indicate not only that pyrrhotite is a cyanicide, but that it robs the cyanide solution of much of its oxygen which is necessary for gold dissolution.

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[12] Dorr, op. cit., pp. 325-326.

[13] Idem., pp. 321-324.

[14] Idem., pp. 365-368.

The treatment of this ore is complicated. An elaborate system of concentration is employed to recover the maximum amount of gold before cyanidation. Fifty-eight per cent of the gold is recovered by concentration methods, and 32 per cent of the gold by cyanidation.

An auxiliary agent for aiding in the dissolution of gold in mispickel ores is bromide of cyanogen, BrCN; this has been used with a certain amount of success. The chief centers in which this has been applied are at the Deloro Mine, Ontario, Canada, and in the Kalgurli district of Western Australia [15].

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[15] Clennell, op. cit., p. 295.

LABORATORY TESTS

Chemical Determinations

Oxygen Dissolved in Solution: The method used for the determination of dissolved oxygen in cyanide solution is the Weinig-Bowen method 16/. The apparatus required for this test are: Two 2 1/2-liter Winchester acid bottles; one 250-cc flask, one 50-cc burette with side connection; one common, 50-cc burette; one clamp stand to hold burettes in position; one 400-cc beaker with the 250-cc point marked on it; one special glass stirring rod; glass tubing (3/16-inch) for connections; rubber tubing for connections; one pinchcock for bottom of the burette that contains standard hydrosulfite solution; one container for kerosene to be used in the procedure.

When the apparatus is set up the relative position of the different parts shown in Plate 1 must be closely followed. As there is a siphoning action from bottle a to bottle b and from bottle b to the burette d, the bottom of bottle a must be above the top of bottle b and

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16/ Weinig, A. J., and Carpenter, C. B., The Trend of Flotation: Colorado School of Mines Quart., vol. 32, no. 4, Oct. 1937, pp. 144-150.

Fig. No. 1: Photograph of Apparatus

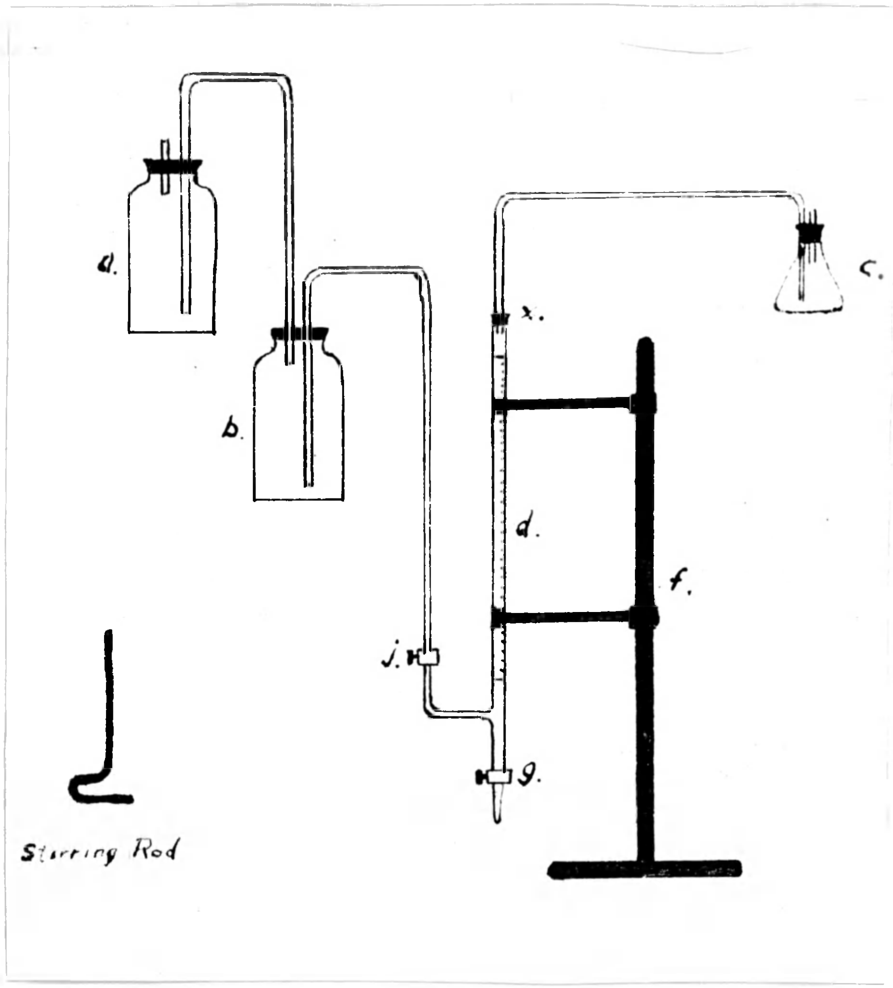

Fig. No. 2:. Illustration of Apparatus

Plate No. 1: Apparatus for Weinig-Bowen Method for Determining Oxygen Dissolved in Solution.

also above the top of the burette *d*; also the bottom of the flask *c* should be above the top of the burette *d*, for convenience. Bottle *b* contains the standard solution; because this standard deteriorates very rapidly, if exposed to the air, the bottle must be sealed air tight.

The bottles are filled in the following manner: Remove the connection *x* and place a cork in the top of the burette *d* so that no solution can overflow. Place a bottle containing 2 1/2 liters of kerosene so that its bottom is above the top of bottle *a* and connect this bottle to the bottom of the burette *d* with a siphon. Open the pinchcock *g* and the stopcock *j* and allow kerosene to siphon into bottle *b* until it is filled. Replace the bottle which contained kerosene by a bottle containing the standard solution of hydrosulfite. This solution should always be covered with a layer of kerosene; siphon the standard solution into bottle *b*, the kerosene being forced from bottle *b* over into bottle *a* automatically. As soon as the standard hydrosulfite solution has reached to within 1 or 2 inches of the top of bottle *b*, close both the pinchcock *g* and the stopcock *j*. After the flask *c* has been nearly filled with kerosene, place the connection *x* in the top of the burette *d* and seal. Open the stopcock *j*, the pinchcock *g* being kept closed, and allow the standard solution to pass into the burette *d* until it just enters the flask *c*; then close the stopcock *j*, open the pinchcock *g*, and allow the standard solution to drain out completely; its action as a siphon will draw the kerosene over into the burette *d*. The standard solution is now drained off so as to eliminate any possibility of its being exposed to air and to give it a cover of kerosene in the burette *d*. Close the pinchcock *g*, open the stopcock *j*, and allow the burette *d* to fill to the zero mark. The layer of kerosene prevents the admission of air during this procedure. Then the apparatus is ready for use.

The standard solution is made up by dissolving 5 grams of sodium hydroxide in a 2 1/2-liter Winchester acid bottle filled with freshly distilled water. When this has been completely dissolved, add 5 grams of sodium hydrosulfite to the solution and immediately place a layer of kerosene over the solution. The caustic soda preserves the hydrosulfite and enters into the reaction during titration.

The indicator, indigotin disulfonate, is made up as follows: Place in a casserole 7 grams of indigotin (indigo blue) and add 30 cc of concentrated sulfuric acid. Place over a water bath and heat to 90 C for 1 1/2 hours, or until all lumps disappear. Then dilute to two liters with distilled water. Neutralize the acidity by adding powdered limestone, small portions at a time. Filter without washing and place in a corked bottle.

The solutions are standardized as follows: Into the clean 400-cc beaker place one drop of phenolphthalein indicator and cover with a 3/4-inch layer of kerosene. Oxygen-saturated water is now siphoned into the beaker below the kerosene. When 250-cc of water have been measured out beneath the kerosene, the alkalinity is neutralized with dilute sulfuric acid from a burette, the tip of which extends below the surface of the solution; 1 cc of the indigotin disulfonate solution is then run in beneath the kerosene. The solution is now titrated with the hydrosulfite solution. The tip of the burette must dip beneath the kerosene so that, by constant stirring with the special stirring rod, any entry of air is avoided. The titration with hydrosulfite first reacts with the dissolved oxygen; as the end point is reached, the hydrosulfite decolorizes the indigo disulfonate, and the end point is yellow or yellowish white. When this point is reached, the burette is read and noted, and 5 cc of indigo disulfonate solution is run in; this is again followed by titration with the hydrosulfite. This operation gives the required relationships between the various solutions.

A sample calculation for standardization of solutions is shown as follows: Assume that the water showed a saturation of 8 mg. per liter, and that the titration gave 9 cc hydrosulfite standard followed by 5.5 cc more, after 5 cc of the indigotin disulfonate standard was added. Then 5 cc indigotin equals 5.5 cc of hydrosulfite; and 1 cc indigotin equals 1.1 cc hydrosulfite. Also, as 1 cc of the indigotin was used at the start, we must correct the first hydrosulfite titration for the 1 cc indigotin used. This correction is 1.1 cc. The amount of hydrosulfite consumed on the dissolved oxygen is 9.0 cc minus 1.1 cc, which is equal to 7.9 cc. Now, 7.9 cc hydrosulfite equals 8 mg. oxygen per liter, or 1 cc hydrosulfite equals 8.0 divided by 7.9 which equals 1.01 mg. oxygen per liter, when 250 cc of the saturated water is titrated. Also, 1 cc indigotin disulfonate standard is equivalent to 1.1 times 1.01, divided by 4 equals 0.28 mg. oxygen.

When the solutions are standardized, the procedure with routine solution titrations is simple. Here, 250 cc of solution is siphoned out beneath a layer of kerosene, and the alkalinity is neutralized with dilute sulfuric acid, 1 cc or less of indigotin disulfonate is added as an indicator, and titration is completed with the hydrosulfite. Following this, the necessary correction is made for the indicator, and the result is converted to milligrams of oxygen per liter of solution.

Free Cyanide: Free cyanide in the solution is found volumetrically, by slowly running silver nitrate solution of a known strength from a burette into a known quantity of the cyanide solution, without using an indicator to determine the end point.

The silver nitrate solution is made up so that 5 cc is equal to 1 pound of free cyanide per ton of solution when using a 10-cc sample of cyanide solution. This is done by dissolving 8.66 grams of silver nitrate ($AgNO_3$) in a liter of distilled water. The end point of the titration is obtained when a distinct blue opalescent cloud persists in the solution. The equation for this reaction is:

$$AgNO_3 + 2\ NaCN \;=\; AgNa(CN)_2 + NaNO_3$$ [17]

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[17] Dorr, op. cit., p. 33.

Alkalinity in Solution: Protective alkalinity of the solution is also determined volumetrically. After the free cyanide has been determined, a drop or two of phenolphthalein indicator is added, which in the presence of alkaline hydrates causes the solution to turn pink. Then oxalic acid of known strength is slowly run into the solution from a burette until the pink color disappears, the end point of the titration. The equation for this reaction is:

$$CaO + H_2C_2O_4 \cdot 2H_2O \;=\; CaC_2O_4 + 3\ H_2O$$ [18]

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[18] Dorr, op. cit., p. 34.

The oxalic acid is made up so that 5 cc is equal to 1 pound of alkali per ton of solution. This is done by dissolving 2.25 grams of oxalic acid in a liter of distilled water and then standardizing this against a standard alkali.

Total Cyanide: The determination of the total cyanide in solution is obtained by a distillation process followed by titration 19/. (Plate 2)

19/ Gisler, H. J., Deco Trefoil, vol. 12, no. 12, Jan.-Feb. 1948, p. 4.

Ten cc of solution is put into a Claissen distillation flask connected to two 500-cc Erlenmeyer flasks in series. The flasks are placed in a cooling bath; each flask contains 150 cc of a 2 per cent sodium hydroxide solution. Fifty cc of hydrochloric acid, diluted 1 to 4 parts distilled water, is added through a separating funnel to the Claissen flask. The contents of the flask is boiled vigorously for at least 6 minutes by placing a Bunsen burner under the Claissen flask. Then the contents of the Erlenmeyer flasks are combined and agitated vigorously with about 1 gram of litharge to remove any soluble sulfides. This solution is filtered, and the filtrate is titrated for cyanide as in the free cyanide determination. The cyanide so determined represents the total cyanide in the original solution.

Agitator Used For Test Work

The agitator (Plate 3) consists of three solid cylindrical wooden rollers, 3 inches in diameter and 24 inches long, fixed parallel in a rectangular box. The first roller has a shaft extending through the box on which a 10-inch wooden pulley is attached. The first and third rollers are connected by belting, the second or center roller turning free. A 1/3-horsepower, 110-volt, constant-speed electric motor connected by a V-belt to a speed reducer in turn connected by belting to the 10-inch pulley provides adequate power to turn the rollers. Pulp is placed in 2 1/2-liter acid bottles, and these are laid longitudinally on the rollers. The bottles rotate at 36 revolutions per minute. The capacity of the agitator is four bottles or tests simultaneously.

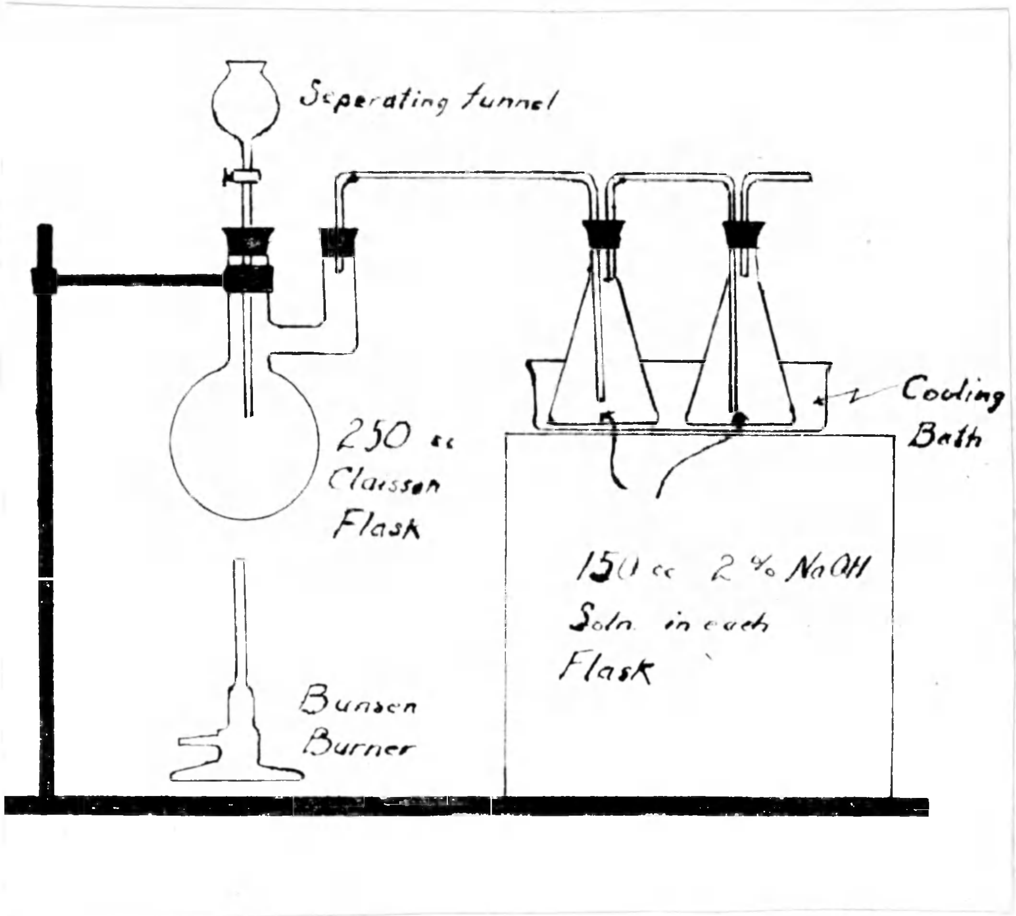

Fig. No. 1: Photograph of Apparatus

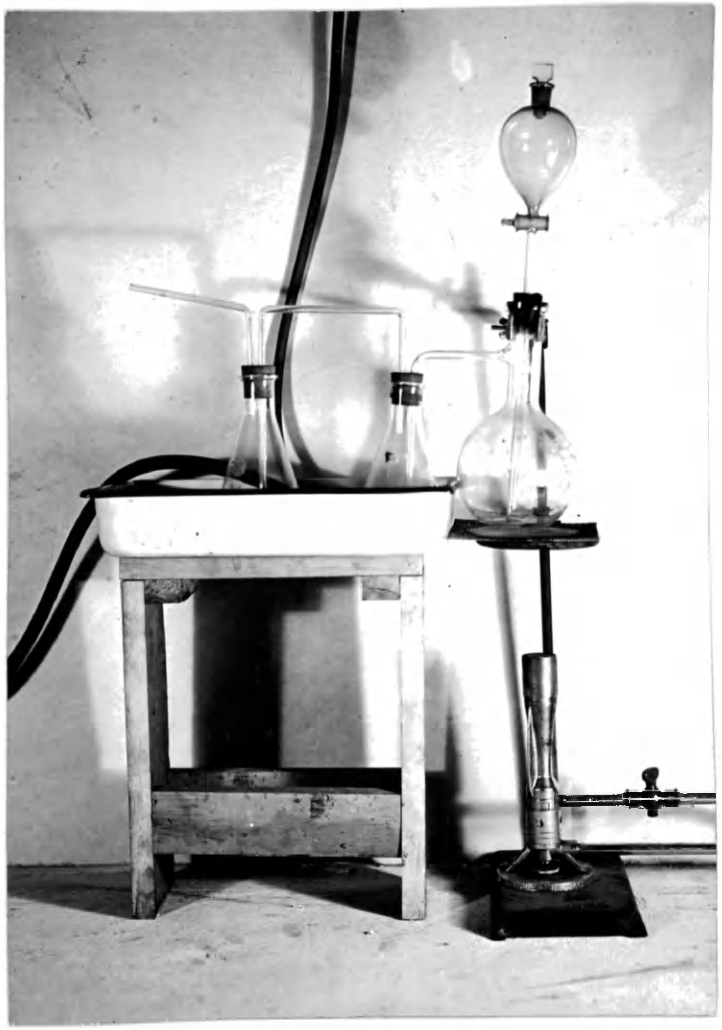

Fig. No. 2: Illustration of Apparatus

Plate No. 2: Apparatus for the Determination of Total Cyanide in Solution

Fig. No. 1: Photograph of Agitator

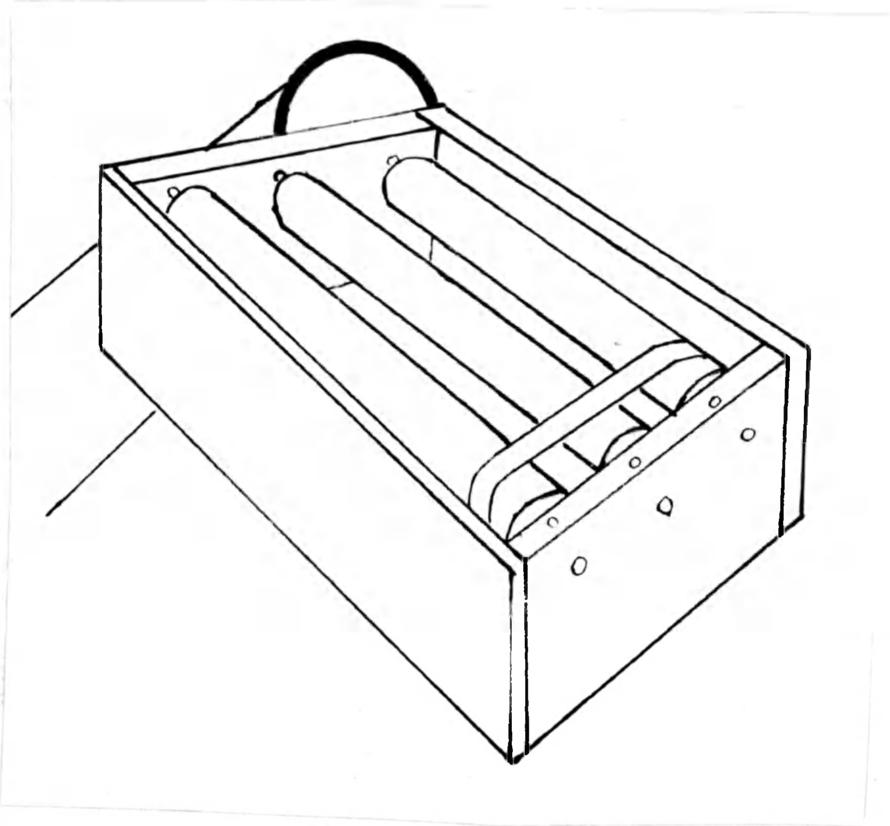

Fig. No. 2: Illustration of Agitator

Plate No. 3: Agitator Used in Cyanidation Tests.

Analysis and Examination of the Ore

In order to determine the minerals present in this ore, specimens were mounted in bakelite molds and by the use of a polarizing microscope, a mineralographic study was made (Plate 4).

Minerals found were:

Pyrite (FeS_2)	Sphalerite (ZnS)
Arsenopyrite ($FeAsS_2$)	Covellite (CuS)
Galena (PbS)	Silica (SiO_2)

As no gold was observed in any of the studies, it may be assumed that it is present sub-microscopically.

A sample of the ground ore was screened through a series of Tyler standard screens to determine the mesh grind for substantial liberation of the minerals. Samples of each product were mounted in bakelite molds and micro-photographed (Plate 5). The mesh grind for liberation of minerals other than gold and silver is minus 48 mesh and plus 65 mesh.

In order to determine the association of gold in the ore, a qualitative spectrographic analysis was performed. This was accomplished by separating mineral grains of galena, pyrite, and arsenopyrite by use of a microscope and exciting a sample of each in the spectrograph. It was found that the gold occurs in both the pyrite and in the arsenopyrite, and that the galena contains no gold but does contain silver.

A complete chemical analysis of the head sample gave the following results:

Lead	9.51 %	Arsenic	8.80 %
Iron	34.32 %	Antimony	0.70 %
Copper	0.31 %	Gold	3.41 oz/ton
Zinc	2.25 %	Silver	11.58 oz/ton

Fig. No. 1: 50x

Arsenopyrite
Sphalerite
Pyrite
Galena

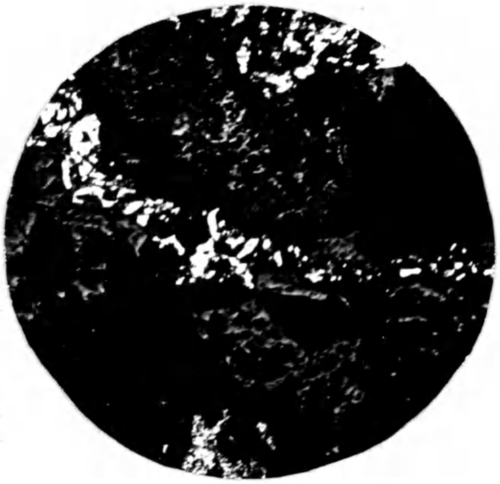

Fig. No. 2: 50x

Arsenopyrite
Sphalerite
Pyrite

Plate No. 4: Ore Specimens Mounted in Bakelite Molds and Polished.

Fig. No. 1: 14 mesh, 100x

Arsenopyrite
Sphalerite
Pyrite

Fig. No. 2: 28 mesh, 100x

Arsenopyrite
Pyrite
Silica

Fig. No. 3: 35 mesh, 100x

Arsenopyrite
Sphalerite
Pyrite
Silica

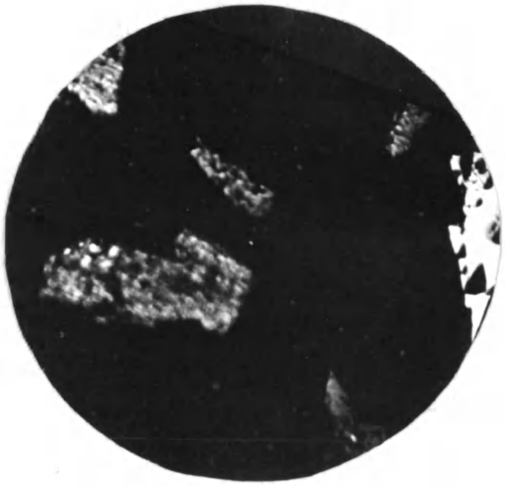

Fig. No. 4: 65 mesh, 100x

Arsenopyrite
Sphalerite
Pyrite
Silica

Plate No. 5: Samples of Screen Analysis Mounted in Bakelite Molds.

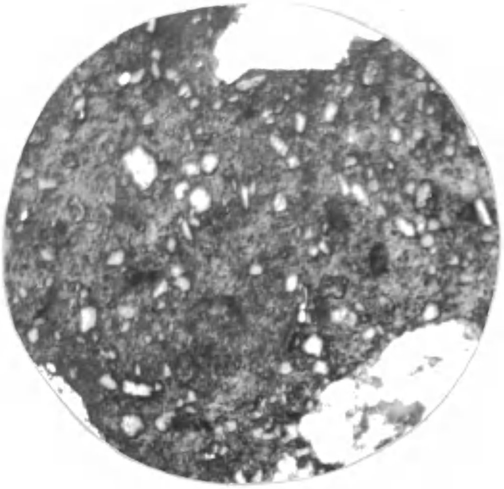

Fig. No. 5: 100 mesh, 100x

Arsenopyrite
Sphalerite
Pyrite

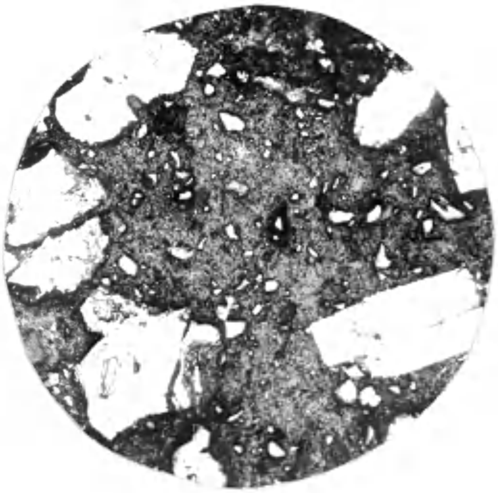

Fig. No. 6: 150 mesh, 100x

Sphalerite
Galena
Pyrite
Silica

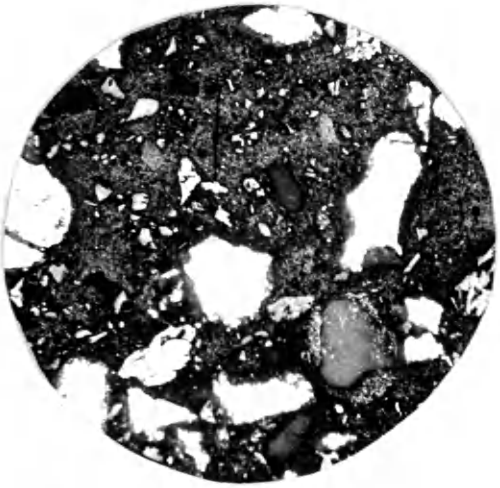

Fig. No. 7: Plus 200 mesh, 100x

Arsenopyrite
Sphalerite
Galena
Pyrite

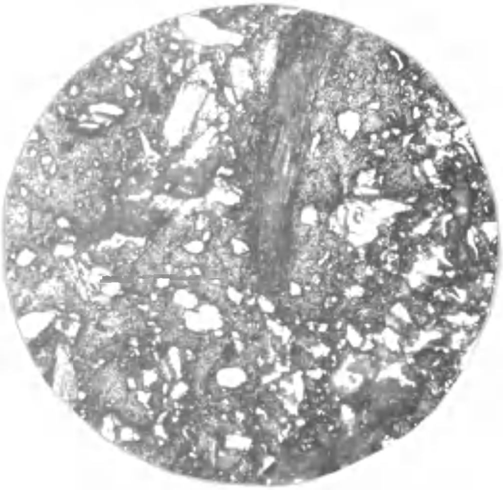

Fig. No. 8: Minus 200 mesh, 100x

Arsenopyrite
Sphalerite
Pyrite
Galena
Silica

Plate No. 5: Samples of Screen Analysis Mounted in Bakelite Molds.

Lime Consumption

In order to determine the amount of lime consumed per ton of ore, 200 grams of ore was agitated with a liter of distilled water for 1 1/2 hours. This was then decanted through a filter and 945 cc of clear solution was recovered. The ore was made up to 1 liter of solution by adding distilled water and a few drops of phenolphthalein. One-half gram of lime was added and the solution again agitated. When observation of the solution showed that the pink color had disappeared (this color is seen when the pulp contains alkalinity), additional amounts of lime were added and in turn observed periodically. At the end of 24 hours, a total of 3.5 grams of lime had been added and the solution remained a pink color. A sample was taken and titrated for protective alkalinity. The result of the titration indicated 0.01 pound of lime per ton of solution.

From this it is evident that the lime consumption is rather high; the consumption is slightly less than 70 pounds of lime per ton of ore.

Preliminary Washes

Water Wash: Two hundred grams of ore and a liter of water were agitated for 1 1/2 hours and then filtered. This wash solution was tested for the presence of iron by adding ammonium hydroxide. This test showed considerable ferrous iron to be present as a dark green precipitate. The pH of the wash solution was 5.1.

Sodium Hydroxide Wash: Two hundred grams of ore and a liter of a 5 per cent sodium hydroxide solution were agitated for 24 hours. The pulp was filtered through a Buchner filter. The filtrate contained 35 grams of sodium hydroxide per liter, thus indicating that 15 grams per liter was used up in dissolving constituents in the ore. Further investigation showed that the solution contained 4.45 grams of lead per liter and 4.89 grams of arsenic per liter. This means that 44.5 pounds of lead and 48.9 pounds of arsenic per ton of ore were dissolved, or that 24.7 per cent of the lead and 27.8 per cent of the arsenic present were dissolved from the ore by this wash.

Sulfuric Acid Wash: Two hundred grams of ore and a liter of a 1 per cent sulfuric acid solution were agitated for 18 hours. The pulp was filtered through a Buchner filter. The filtrate was found to contain 4.21 grams of arsenic per liter of solution. This means that 42.1 pounds of arsenic per ton of ore, or 23.9 per cent of the arsenic, was dissolved by this acid wash.

Cyanidation Tests

General Procedure: Cyanidation tests were performed by taking 200-gram samples of the ore, which had been crushed and ground to minus 65 mesh, without introducing water. The ore was placed in Winchester acid bottles and 600 cc of cyanide solution added. Sufficient lime to provide protective alkalinity was combined and mixed with the dry ore used in the test. The period of time for leaching was generally 24 hours. Samples were taken during the tests to determine whether free cyanide and protective alkalinity were sufficiently high. A stock solution of cyanide containing 3 pounds of sodium cyanide and 2 pounds of lime per ton of solution was prepared to facilitate the tests.

The procedure and results for each test are detailed individually in the pages that follow.

Test No. 1: The ore used in this test was the product from the sodium hydroxide wash. After the sodium hydroxide was thoroughly washed out, the ore contained approximately 30 cc of water. Then, 550 cc of distilled water, 20 cc of 5-per-cent sodium cyanide solution, and 1 gram of lime were added.

At the end of 1 hour the solution was tested and found to contain 2.05 lb of free cyanide and 1.0 lb of alkali per ton of solution. An additional 5 cc of 5-per-cent sodium cyanide was added at this point.

At the end of 24 hours the test was stopped and the solution again tested; it was found to contain 1.50 lb of free cyanide and 0.96 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	4.18	3.34	12.50	10.00
Remaining	1.50	0.96	4.45	2.88
Consumed	2.68	2.38	8.05	7.12

Gold Extraction

Head Assay........3.41 oz per ton

Tails Assay.......1.88 oz per ton

$$\text{Extraction} = \frac{(3.41 - 2.56) \times 100}{3.41} = 45.0\ \%$$

<u>Test No. 2</u>: The ore used in this test was the product from the sulfuric acid wash. After the acid was thoroughly washed out with water, the ore contained approximately 30 cc of water. Then, 550 cc of distilled water was added, and the solution was neutralized by adding lime in small amounts until a total of 2 grams was added. At this time 1 additional gram of lime was added to provide protective alkalinity. Finally, 20 cc of 5-per-cent sodium cyanide wolution was added.

At the end of 1 hour the solution was tested and found to contain 2.40 lb of free cyanide per ton of solution and no alkali. An additional 5 cc of 5-per-cent sodium cyanide solution and 1 gram of lime were added.

The solution was tested again at the end of 2 hours and found to contain 3.00 lb of free cyanide and 0.20 lb of alkali per ton of solution; it was tested again at the end of 3 1/2 hours and found to contain 2.30 lb of free cyanide and 0.50 lb of alkali per ton of solution. No cyanide was added at the end of 2 hours, but 1 gram of lime was added. At the end of 3 1/2 hours, 5 cc of 5-per-cent sodium cyanide solution, and another gram of lime were added. Also, 30 cc of distilled water was added to make 600 cc of solution.

At the end of 24 hours the test was stopped and the solution tested again; it was found to contain 1.20 lb of free cyanide and 0.60 lb of alkali per ton of solution.

<u>Reagent Consumption</u>

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	5.00	20.00	15.00	60.00
Remaining	1.20	0.60	3.60	1.80
Consumed	3.80	19.40	11.40	58.20

Gold Extraction

Head Assay.........3.41 oz per ton

Tails Assay........2.34 oz per ton

$$\text{Extraction} = \frac{(3.41 - 2.34) \times 100}{3.41} = 31.4\ \%$$

Test No. 3: The ore used in this test was the product from the water wash. After this wash was thoroughly removed the ore contained approximately 50 cc of water. Then, 530 cc of distilled water, 20 cc of 5-per-cent sodium cyanide solution, and 1 gram of lime were added.

At the end of 1 hour the solution was tested and found to contain 2.85 lb of free cyanide and 0.28 lb of alkali per ton of solution. An additional 0.8 gram of lime was added at this point.

At the end of 24 hours the test was stopped, and again the solution was tested; it was found to contain 0.95 lb of free cyanide and 0.10 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	3.34	6.00	10.00	18.00
Remaining	0.95	0.10	2.85	0.30
Consumed	2.39	5.90	7.15	17.70

Gold Extraction

Head Assay.........3.41 oz per ton

Tails Assay........2.56 oz per ton

$$\text{Extraction} = \frac{(3.41 - 2.56) \times 100}{3.41} = 24.9\ \%$$

Test No. 4: In this test 200 grams of minus 65 mesh plus 100 mesh ore was mixed with the stock cyanide solution. After 15 minutes, an additional 5 grams of lime was added.

At the end of 1 hour the solution was tested and found to contain 2.35 lb of free cyanide and 2.74 lb of alkali per ton of solution. Here, 4 cc of 5-per-cent sodium cyanide solution and 5 grams of lime were added.

At the end of 18 hours the solution was tested and found to contain 2.04 lb of free cyanide and 2.38 lb of alkali per ton of solution. To this, 6 cc of 5-per-cent sodium cyanide solution was added.

At the end of 24 hours the test was stopped, and again the solution was tested; it was found to contain 2.84 lb of free cyanide and 2.40 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	4.67	35.34	14.00	106.00
Remaining	2.84	2.40	8.52	7.20
Consumed	1.83	32.94	5.48	98.80

Gold Extraction

Head Assay.........3.08 oz per ton

Tails Assay........2.08 oz per ton

$$\text{Extraction} = \frac{(3.08 - 2.08) \times 100}{3.08} = 32.5\ \%$$

<u>Test No. 5</u>: In this test 200 grams of minus 100 mesh plus 200 mesh ore was mixed with the stock cyanide solution. After 15 minutes, an additional 5 grams of lime was added.

At the end of 1 hour the solution was tested and found to contain 0.90 lb of free cyanide and 2.30 lb of alkali per ton of solution. Here, 14 cc of 5-per-cent sodium cyanide solution and 5 grams of lime were added.

At the end of 18 hours the solution was tested and found to contain 2.62 lb of free cyanide and 2.86 lb of alkali per ton of solution. To this, 3 cc of 5-per-cent sodium cyanide solution was added.

At the end of 24 hours the test was stopped, and again the solution was tested; it was found to contain 3.04 lb of free cyanide and 2.80 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	5.84	35.34	17.50	106.00
Remaining	3.04	2.80	9.12	8.40
Consumed	2.80	32.54	8.38	97.60

Gold Extraction

Head Assay.........3.80 oz per ton

Tails Assay........3.40 oz per ton

$$\text{Extraction} = \frac{(3.80 - 3.40) \times 100}{3.80} = 10.5\ \%$$

Test No. 6: In this test 200 grams of minus 200 mesh plus 325 mesh ore was mixed with the stock cyanide solution. After 15 minutes, an additional 5 grams of lime was added.

At the end of one hour the solution was tested and found to contain 0.04 lb of free cyanide and 1.04 lb of alkali per ton of solution. Here, 20 cc of 5-per-cent sodium cyanide solution and 5 grams of lime were added.

At the end of 18 hours the solution was tested and found to contain 2.44 lb of free cyanide and 2.56 lb of alkali per ton of solution. To this, 4 cc of 5-per-cent sodium cyanide solution was added.

At the end of 24 hours the test was stopped, and again the solution was tested; it was found to contain 2.96 lb of free cyanide and 2.60 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	7.00	35.34	21.00	106.00
Remaining	2.96	2.60	8.88	7.80
Consumed	4.04	32.74	12.12	98.20

Gold Extraction

Head Assay........4.56 oz per ton

Tails Assay.......3.72 oz per ton

$$\text{Extraction} = \frac{(4.56 - 3.72) \times 100}{4.56} = 18.4\ \%$$

Test No. 7: In this test 200 grams of minus 325 ore was mixed with the stock cyanide solution. After 15 minutes, an additional 5 grams of lime was added.

At the end of 1 hour the solution was tested and found to contain 0.08 lb of free cyanide and 0.06 lb of alkali per ton of solution. Here, 20 cc of 5-per-cent sodium cyanide solution and 5 grams of lime were added.

At the end of 18 hours the solution was tested and found to contain 1.62 lb of free cyanide and 1.86 lb of alkali per ton of solution. To this, 9 cc of 5-per-cent sodium cyanide solution was added.

At the end of 24 hours the test was stopped, and again the solution was tested; it was found to contain 2.74 lb of free cyanide and 3.04 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	7.84	35.34	23.52	106.00
Remaining	2.74	3.04	8.22	9.12
Consumed	5.10	32.30	15.30	96.88

Gold Extraction

Head Assay.........3.76 oz per ton

Tails Assay........3.44 oz per ton

$$\text{Extraction} = \frac{(3.76 - 3.44) \times 100}{3.76} = 8.5\ \%$$

Test No. 8: In this test 200 grams of ore was mixed with 6 grams of lime and 600 cc of calcium cyanide ($Ca(CN)_2$) solution, containing 17 lb of free cyanide per ton of solution.

At the end of 24 hours the test was stopped, and the solution was tested; it was found to contain 12.64 lb of free cyanide and 1.0 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	17.00	20.00	51.00	60.00
Remaining	12.64	1.00	37.92	3.00
Consumed	4.36	19.00	13.08	57.00

Gold Extraction

Head Assay.........4.00 oz per ton

Tails Assay........1.44 oz per ton

$$\text{Extraction} = \frac{(4.00 - 1.44) \times 100}{4.00} = 64.0\ \%$$

The Monomolecular Law constant (K) was determined, and from this it was calculated that 90 per cent of the gold would be leached from the ore in 54 hours.

$$K = \frac{2.3 \text{ Log } a/a-x}{t}$$

Where: a is original amount
x is amount removed
t is time (min., hr., days)

The pregnant solution was tested to determine the amount of oxygen dissolved; it was found to contain 1.55 mg of oxygen per l. From this it was calculated to be 20.7 per cent saturated.

The pregnant solution was divided, and half was precipitated with zinc dust, and the other half was precipitated with aluminum dust. Each solution was tested to determine the amount of oxygen dissolved after precipitation. The solution which had been precipitated with zinc dust was found to contain 0.60 mg of oxygen per l. From this it was calculated to be 8.0 per cent saturated. The solution which had been precipitated with aluminum dust was found to contain 3.01 mg of oxygen per l. From this it was calculated to be 40.0 per cent saturated.

Test No. 9: In this test 200 grams of ore was mixed with 7 grams of lime and 600 cc of calcium cyanide ($Ca(CN)_2$) solution, containing 17 lb of free cyanide per ton of solution.

At the end of 48 hours the test was stopped, and the solution was tested; it was found to contain 12.14 lb of free cyanide, 13.50 lb of total cyanide, and 0.96 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	17.00	23.34	51.00	70.00
Remaining	12.14	0.96	36.42	2.98
Consumed	4.86	22.38	14.58	67.12

Gold Extraction

Head Assay.........4.00 oz per ton

Tails Assay........1.46 oz per ton

$$\text{Extraction} = \frac{(4.00 - 1.48) \times 100}{4.00} = 63.5\ \%$$

Monomolecular Law constant (K) was determined, and from this it was calculated that 90 per cent of the gold would be leached from the ore in 108 hours.

The pregnant solution was tested to determine the amount of oxygen dissolved; it was found to be 0.09 mg of oxygen per l. From this it was calculated to be 1.12 per cent saturated. Then, the solution was precipitated with zinc dust and again tested to determine the amount of oxygen dissolved; it was found to contain no oxygen.

Test No. 10: In this test 200 grams of ore was mixed with 5 grams of lime and 600 cc of sodium cyanide solution containing 3 lb of free cyanide and 0.68 lb of lime per ton of solution.

At the end of 1 hour the solution was tested and found to contain 2.30 lb of free cyanide and 1.06 lb of alkali per ton of solution. Here, 2 grams of lime was added.

At the end of 17 hours the solution was tested and found to contain 1.20 lb of free cyanide and 1.58 lb of alkali per ton of solution. To this, 10.8 cc of 5-per-cent sodium cyanide solution was added.

At the end of 24 hours the test was stopped, and again the solution tested; it was found to contain 2.25 lb of free cyanide and 1.34 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	4.10	24.02	12.30	72.06
Remaining	2.25	1.34	6.75	4.02
Consumed	1.85	22.68	5.55	68.04

Gold Extraction

Head Assay.........4.00 oz per ton

Tails Assay........2.69 oz per ton

$$\text{Extraction} = \frac{(4.00 - 2.64) \times 100}{4.00} = 32.7\ \%$$

Test No. 11: In this test 200 grams of ore was mixed with 5 grams of lime and 600 cc of pregnant solution which had been precipitated with zinc dust and containing 3 lb of free cyanide and 1 lb of alkali per ton of solution.

At the end of 1 hour the solution was tested and found to contain 2.10 lb of free cyanide and 1.84 lb of alkali per ton of solution.

At the end of 17 hours the solution was tested and found to contain 1.30 lb of free cyanide and 0.51 lb of alkali per ton of solution. To this, 10.2 cc of 5-per-cent sodium cyanide solution and 0.25 gram of lime were added.

At the end of 24 hours the test was stopped, and again the solution tested; it was found to contain 2.65 lb of free cyanide and 0.62 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	4.70	18.50	14.10	55.50
Remaining	2.65	0.62	7.95	1.86
Consumed	2.05	17.88	6.15	53.64

Gold Extraction

Head Assay.........4.00 oz per ton

Tails Assay........2.69 oz per ton

$$\text{Extraction} = \frac{(4.00 - 2.69) \times 100}{4.00} = 32.7\ \%$$

Test No. 12: In this test 200 grams of ore was mixed with 6 grams of lime, 21.8 cc of 5-per-cent sodium cyanide solution, and 578.2 cc of distilled water.

At the end of 1 hour the solution was tested and found to contain 3.05 lb of free cyanide and 1.06 lb of alkali per ton of solution.

At the end of 17 hours the solution was tested and found to contain 1.60 lb of free cyanide and 0.44 lb of alkali per ton of solution. To this, 9.6 cc of 5-per-cent sodium cyanide solution and 0.22 grams of lime were added.

At the end of 24 hours the test was stopped, and again the solution tested; it was found to contain 1.90 lb of free cyanide and 0.38 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	5.07	20.74	15.21	62.22
Remaining	1.90	0.38	5.70	1.14
Consumed	3.13	20.36	9.51	61.08

Gold Extraction

Head Assay.........4.00 oz per ton

Tails Assay........2.21 oz per ton

$$\text{Extraction} = \frac{(4.00 - 2.21) \times 100}{4.00} = 44.7\ \%$$

Test No. 13: In this test 200 grams of Golden Cycle calcines and 600 cc of stock solution, containing 3 lb of free cyanide and 1 lb of alkali per ton of solution, were agitated for 24 hours.

At the end of 1 hour the solution was tested and found to contain 2.67 lb of free cyanide and 0.40 lb of alkali per ton of solution. Here, 2 grams of lime was added.

At the end of 24 hours the test was stopped, and again the solution was tested; it was found to contain 2.46 lb of free cyanide and 1.62 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	3.00	7.67	9.00	23.00
Remaining	2.46	1.62	7.38	4.86
Consumed	0.54	6.05	1.62	18.14

Gold Extraction

Head Assay.........0.42 oz per ton

Tails Assay........0.08 oz per ton

$$\text{Extraction} = \frac{(0.42 - 0.08) \times 100}{0.42} = 81.0\ \%$$

The pregnant solution was tested to determine the amount of oxygen dissolved; it was found to be 7.33 mg of oxygen per l. From this it was calculated to be 91.6 per cent saturated.

Test No. 14: In this test 200 grams of Golden Cycle calcines and 600 cc of stock cyanide solution, containing 3 lb of free cyanide and 1 lb of alkali per ton of solution, were agitated for 68 hours.

At the end of 1 hour the solution was tested and found to contain 2.72 lb of free cyanide and 0.40 lb of alkali per ton of solution. Here, 2 grams of lime was added.

At the end of 68 hours the test was stopped, and again the solution was tested; it was found to contain 2.68 lb of free cyanide and 0.32 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	3.00	7.67	9.00	23.00
Remaining	2.68	0.32	8.04	0.96
Consumed	0.32	7.35	0.96	22.04

Gold Extraction

Head Assay.........0.42 oz per ton

Tails Assay........0.05 oz per ton

$$\text{Extraction} = \frac{(0.42 - 0.05) \times 100}{0.42} = 88.2\ \%$$

The pregnant solution was tested to determine the amount of oxygen dissolved; it was found to be 5.40 mg of oxygen per l. From this it was calculated to be 67.5 per cent saturated.

Test No. 15: This test was designed to determine the effects of the re-use of barren solution. In this test 200 grams of the ore was mixed with 7 grams of lime and 600 cc of stock cyanide solution, containing 2.94 lb of free cyanide and 0.70 lb of alkali per ton of solution, and was agitated for 24 hours. The stock cyanide solution was saturated with oxygen and contained 6.19 mg per l.

At the end of 24 hours the solution was tested and found to contain 0.68 lb of free cyanide and 1.50 lb of alkali per ton of solution. The pulp was filtered through a Buchner filter and precipitated with zinc dust. The solution was tested and found to contain 0.46 lb of free cyanide and 1.40 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	2.94	24.04	8.82	72.12
Remaining	0.46	1.50	1.38	4.50
Consumed	2.48	22.54	7.44	67.62

Gold Extraction

Head Assay..........4.00 oz per ton

Tails Assay.........3.08 oz per ton

$$\text{Extraction} = \frac{(4.00 - 3.08) \times 100}{4.00} = 23.0\ \%$$

The barren solution was added to 200 grams of fresh ore and 6 grams of lime. The solution was made up to 3.30 lb of free cyanide per ton of solution by adding 20 cc of 5-per-cent sodium cyanide solution.

At the end of 40 hours the pulp was filtered through a Buchner filter; the solution was precipitated with zinc dust and was then tested and found to contain 0.20 lb of free cyanide and 0.22 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	3.30	21.40	9.90	64.20
Remaining	0.20	0.22	0.60	0.66
Consumed	3.10	21.18	9.30	63.54

Gold Extraction

Head Assay.........4.00 oz per ton

Tails Assay........2.72 oz per ton

$$\text{Extraction} = \frac{(4.00 - 2.72) \times 100}{4.00} = 30.0\ \%$$

The Monomolecular Law constant (K) was determined, and from this it was calculated that 20.5 per cent of the gold would be leached from the ore in 24 hours.

The barren solution was added to 200 grams of fresh ore and 7 grams of lime. The solution was made up to 2.94 lb of free cyanide per ton of solution by adding 20 cc of 5-per-cent sodium cyanide solution.

At the end of 24 hours the solution was tested and found to contain 1.02 lb of free cyanide and 1.34 lb of alkali per ton of solution. The pulp was filtered through a Buchner filter and the solution was precipitated with zinc dust. It was tested and found to contain 0.72 lb of free cyanide and 1.30 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	2.94	23.54	8.82	70.62
Remaining	0.72	1.30	2.16	3.90
Consumed	2.22	22.24	6.66	66.72

Gold Extraction

Head Assay.........4.00 oz per ton

Tails Assay........2.84 oz per ton

$$\text{Extraction} = \frac{(4.00 - 2.84) \times 100}{4.00} = 29.0\ \%$$

The barren solution was added to 200 grams of Golden Cycle calcines and 2 grams of lime. The solution was made up to 2.26 lb of free cyanide per ton of solution by adding 10 cc of 5-per-cent sodium cyanide solution.

At the end of 24 hours the pulp was filtered through a Buchner filter and the solution was precipitated with zinc dust. It was tested and found to contain 0.46 lb of free cyanide and 0.54 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	2.26	7.97	6.78	23.91
Remaining	0.46	0.54	1.38	1.62
Consumed	1.80	7.43	5.40	22.29

Gold Extraction

Head Assay.........0.42 oz per ton

Tails Assay........0.03 oz per ton

$$\text{Extraction} = \frac{(0.42 - 0.03) \times 100}{0.42} = 93.0\ \%$$

The barren solution was added to 200 grams of fresh Golden Cycle calcines and 2 grams of lime. The solution was made up to 3.76 lb of free cyanide per ton of solution by adding 20 cc of 5-per-cent sodium cyanide solution.

At the end of 24 hours the pulp was filtered through a Buchner filter and the solution was precipitated with zinc dust. It was tested and found to contain 3.38 lb of free cyanide and 0.38 lb of alkali per ton of solution.

Reagent Consumption

	Pounds per ton of solution		Pounds per ton of ore	
	Cyanide	Lime	Cyanide	Lime
Added	3.76	7.21	11.28	21.63
Remaining	3.38	0.38	10.14	1.04
Consumed	0.38	6.83	1.14	20.59

Gold Extraction

Head Assay.........0.42 oz per ton

Tails Assay........0.01 oz per ton

$$\text{Extraction} = \frac{(0.42 - 0.01) \times 100}{0.42} = 97.6\ \%$$

The pregnant solution was tested to determine the amount of oxygen dissolved; it was found to be 2.52 mg of oxygen per 1. From this it was calculated to be 34.4 per cent saturated.

Oxygen Consumption

The amount of oxygen used in leaching of the ore was determined. This was accomplished by placing ore in a Winchester bottle and stoppering the bottle with a two-hole rubber stopper. Through one hole a length of glass tubing extended to the bottom of the bottle; through the other, a short length of glass tubing extended slightly into the bottle. To the external end of the glass tubing short sections of rubber tubing were sealed, with a pinch-cock on each. The bottle was made air-tight by sealing the stopper and tubing with shellac and by connecting the ends of the rubber tubing with a short length of glass tubing (Plate 6).

The stock cyanide solution was added through the tubing extending to the bottom of the bottle, and thus the air was allowed to escape through the short length of tubing. After the solution had been added, the tubing was sealed off by securing the pinch-cocks tightly.

The bottle was then agitated on the roller agitator.

At the end of the period of agitation the short length of tubing was attached to a manometer, the pinch-cock opened, and the amount of vacuum observed. Then the volume of air in the bottle was determined by adding a known amount of water until the bottle was filled. By assuming that only the oxygen in the air was used in the leaching, the amount consumed could be determined.

The percentage of oxygen in the air was also obtained by an Orsat analysis. However, this could not be done on the same sample used in the above method.

The results of these tests are tabulated on the following pages.

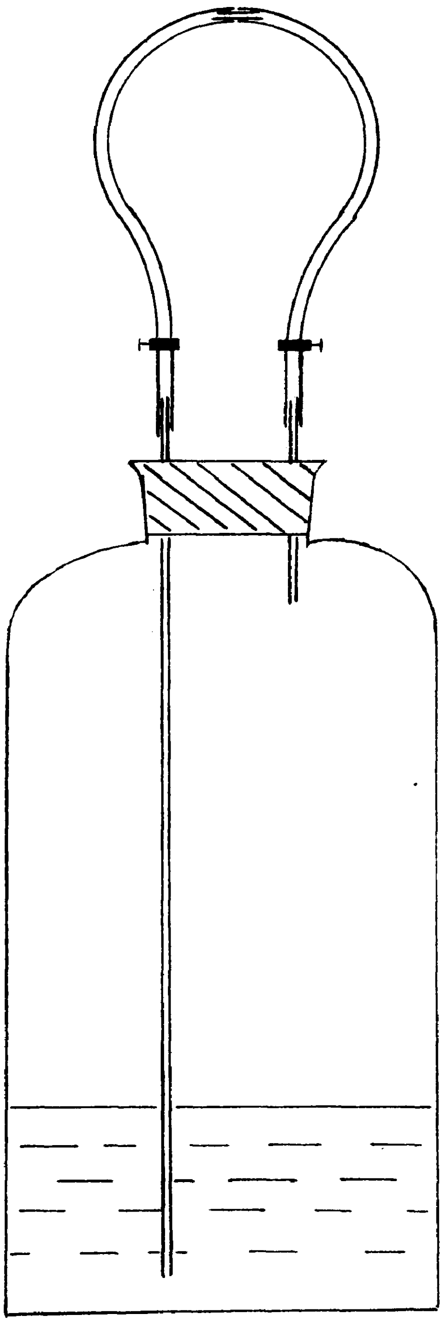

Plate No. 6: Illustration of Apparatus Used in Oxygen Consumption Tests

Test No. 1: In this test 200 grams of Golden Cycle calcines, 2 grams of lime, and 600 cc of oxygen-saturated cyanide solution were sealed in the special Winchester bottle and agitated for 46 hours. At the end of this time the bottle was attached to a manometer and a vacuum of 29.0 mm of Hg was measured.

The volume of gas in the bottle at the start of the test was found to be 1777 cc.

Standard conditions during the test

	Temperature (Degrees F)	Atmospheric Pressure (mm Hg)
Start	67	610.00
Finish	62	617.00

Calculations

Volume of oxygen in the bottle at the start of the test:

$$1777 \times 20.91 = 371.5 \text{ cc}$$

Volume of gas remaining in the bottle:

$$\frac{617.0 - 29.0}{610.0} \times 1777 = 1683 \text{ cc}$$

Volume of gas (oxygen) consumed)

$$1777 - 1683 = 94 \text{ cc}$$

Percentage of the original oxygen present consumed:

$$\frac{94}{371.5} \times 100 = 25.30 \%$$

Test No. 2: In this test 200 grams of Golden Cycle calcines, 2 grams of lime, and 600 cc of oxygen-saturated cyanide solution were sealed in the special Winchester bottle and agitated for 48 hours. At the end of this time the bottle was attached to a manometer and a vacuum of 15.0 mm of Hg was measured.

The volume of gas in the bottle at the start of the test was found to be 1840 cc.

Standard conditions during the test

	Temperature (Degrees F)	Atmospheric Pressure (mm Hg)
Start	66	614.2
Finish	72	617.7

Calculations

Volume of oxygen in the bottle at the start of the test:

$$1840 \times 20.91 = 385.0 \text{ cc}$$

Volume of gas remaining in the bottle:

$$\frac{614.2 - 15.0}{617.7} \times 1840 = 1784 \text{ cc}$$

Volume of gas (oxygen) consumed:

$$1840 - 1784 = 56 \text{ cc}$$

Percentage of the original oxygen present consumed:

$$\frac{56}{385} \times 100 = 14.55 \%$$

<u>Test No. 3</u>: In this test 200 grams of Golden Cycle calcines, 2 grams of lime, and 600 cc of oxygen-saturated cyanide solution were sealed in the special Winchester bottle and agitated for 66 hours. At the end of this time an Orsat analysis was performed on the gas in the bottle to determine the percentage of oxygen; it was found to contain 18.3 per cent oxygen.

The volume of gas in the bottle at the start of the test was found to be 1812 cc.

Standard conditions during the test

	Temperature (Degrees F)	Atmospheric Pressure (mm Hg)
Start	66	614.2
Finish	76	618.9

Calculations

Volume of oxygen in the bottle at the start of the test:

$$1812 \times 20.91 = 378.5 \text{ cc}$$

Volume of oxygen in the bottle at the finish of the test:

$$1812 \times 18.30 = 332.0 \text{ cc}$$

Volume of oxygen consumed:

$$378.5 - 332.0 = 46.5 \text{ cc}$$

Percentage of the original oxygen present consumed:

$$\frac{46.5}{378.5} \times 100 = 12.29 \%$$

Test No. 4: In this test 200 grams of the ore, 7 grams of lime, and 600 cc of oxygen-saturated cyanide solution were sealed in the special Winchester bottle and agitated for 46 hours. At the end of this time the bottle was attached to a manometer and a vacuum of 19.0 mm of Hg was measured.

The volume of gas in the bottle at the start of the test was found to be 1832 cc.

Standard conditions during the test

	Temperature (Degrees F)	Atmospheric Pressure (mm Hg)
Start	71	616.5
Finish	73	619.3

Calculations

Volume of oxygen in the bottle at the start of the test:

$$1832 \times 20.91 = 383.0 \text{ cc}$$

Volume of gas remaining in the bottle:

$$\frac{616.5 - 19.0}{619.3} \times 1832 = 1780 \text{ cc}$$

Percentage of the original oxygen present consumed:

$$\frac{52}{383} \times 100 = 13.58 \%$$

Test No. 5: In this test 200 grams of the ore, 7 grams of lime, and 600 cc of oxygen-saturated cyanide solution were sealed in the special Winchester bottle and agitated for 46 hours. At the end of this time an Orsat analysis was performed on the gas in the bottle to determine the percentage of oxygen, sulfur dioxide, and carbon dioxide present; it was found to contain 18.1 per cent oxygen and no sulfur dioxide or carbon dioxide.

The volume of gas in the bottle at the start of the test was found to be 1813 cc.

Standard conditions during the test

	Temperature (Degrees F)	Atmospheric Pressure (mm Hg)
Start	71	616.5
Finish	73	619.3

Calculations

Volume of oxygen in the bottle at the start of the test:

$$1813 \times 20.91 = 378.4 \text{ cc}$$

Volume of oxygen in the bottle at the finish of the test:

$$1813 \times 1810 = 328.0 \text{ cc}$$

Volume of oxygen consumed:

$$378.4 - 328.0 = 50.4 \text{ cc}$$

Percentage of the original oxygen present consumed:

$$\frac{50.4}{378.4} \times 100 = 13.33 \%$$

CONCLUSION

The foregoing cyanidation tests indicate that an efficient extraction of gold from this ore was not obtained. However, the author believes that these investigations do indicate several points where additional research will improve the extraction.

In the sodium hydroxide wash, arsenic was dissolved from the ore. Therefore, it appears that compounds of arsenic are soluble in alkaline solutions. However, with tests performed on pregnant solutions, which were made alkaline by the addition of lime, no trace of arsenic could be found. This was investigated extensively, by both chemical and spectroscopic methods. The distillation method for the quantitative analysis of arsenic was performed on the solution in amounts varying from 25 cc to 250 cc; no arsenic was detected. The solution was taken to dryness on a hot plate, and the salts remaining were analyzed by use of the spectroscope; arsenic was not found to be present. As it was thought that the arsenic might have been driven off by drying the solution on the hot plate, the solution was placed in carbon electrodes and was allowed to dry slowly, then excited with the spectroscope, and the spectrum was analyzed. Again, no arsenic was found to be present.

The following is offered as a possible explanation for the absence of arsenic in the pregnant solution: Arsenic is dissolved by sodium hydroxide to form soluble sodium arsenate, Na_3AsO_4, formed from the ionized sodium cyanide; the sodium arsenate is precipitated as quickly as taken into solution by calcium ions to form an insoluble calcium-arsenic compound, $Ca_4As_2O_9$. If this possibility exists, then a more efficient sodium hydroxide wash followed by leaching without the addition of lime, might conceivably improve the extraction. It would remove the arsenic from the ore, which is universally considered a hindrance in cyanidation.

By using a relative high concentration of calcium cyanide, a much better extraction was obtained. The use of such concentrations should be investigated more thoroughly, with special attention given to the ratio of free cyanide to the amount of dissolved arsenic, antimony, lead, and copper. Gisler 20/ cites the cyanidation of a difficult cyaniding ore in which the gold extraction was improved by maintaining a ratio of four parts free cyanide to one part dissolved metal. With a high concentration of cyanide there would be increased cost of chemicals, but, with an ore as high in gold as this, the increased extraction would more than overcome these increased costs. Maintaining of so high a ratio of free cyanide to dissolved interfering metals might permit reusing the solutions. The fouling of solutions will be eliminated, it is said, by maintaining a high ratio. This fact was partially verified by these investigations, but because of the over-all low extraction obtained, this fact was not clearly defined. It can be seen, however, from these investiga-

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20/ Gisler, op. cit., p. 4.

tions that the so-called fouled solutions can be re-used to obtain a good recovery from a free-cyaniding ore, as was done for the Golden Cycle calcines.

The highly controversial issue of the role of oxygen in cyanidation was given considerable thought. This is a most interesting issue, but no definite conclusions in this respect can be drawn from this work. However, from the oxygen consumption tests it is seen that approximately 13 per cent of the oxygen present was used up. The procedure used in these tests did not allow the solution to be tested to determine the amount of oxygen dissolved in solution. This, if done, would have proved interesting. Elsner's equation has been accepted, but what is there to prevent an intermediate reaction like the following from taking place without oxygen?

$$Au - NaCN - H_2O = AuCN - NaOH - \frac{1}{2} H_2$$

The strong alkali in turn might dissolve the aurocyanide to form the well-known sodium aurocyanide, $NaAu(CN)_2$. Julian and Smart [21]/ stated that in their work they have found hydrogen to be present on the cathode. If this were the case, then the role of oxygen would be merely that of a depolarizing agent. Further investigation on this point would require more complete equipment and very close control of the many factors, but would help to clear up many yet unanswered questions in the dissolution of gold and silver.

The amount of oxygen necessary for the dissolution of gold varies from 2 1/2 to 6 mg of oxygen per l. But with this ore the amount of oxygen was well under this figure. This bears out the statement that the presence of arsenic in ore denudes the solution of dissolved oxygen.

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[21]/ Julian and Smart, op. cit., p. 70.

The effect of zinc dust versus aluminum dust precipitation brought out the fact that aluminum does not take the oxygen out of precipitated solutions as does the zinc dust. A further investigation of this might conceivably help in overcoming the problem of re-use of solutions after precipitation. Reducing agents, it is known, will denude the solution of dissolved oxygen and reduce the efficiency of extraction when used over again. The relationship of these denuding substances with zinc is another subject requiring more investigation. It might be concluded that arsenic compounds are reducing agents, as they act as such in these tests.

Lime consumption is rather high with this ore, averaging from 60 to 70 pounds per ton of ore. This being so, limestone deposits near the mining operation should be located and burned to produce lime for use in the mill. Available alkalinity in the lime was not determined; accordingly, the lime consumption figure may vary with other limes containing more or less available alkali.

As a final conclusion to this problem, I would say that if it were possible to make a selective lead-zinc flotation, keeping the pyrite and arsenopyrite depressed, and then roasting the tails from flotation with the type of roaster developed by the Dorr Company in the "Fluosolids Process" 22/, this followed by cyanidation of the calcines, a good monetary recovery would be obtained.

22/ Ramsey, R. H., Research and Development Open New Phase in Milling: Eng. and Min. Jour., vol. 149, no. 2, 1948, pp. 104-109.

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