EXPERIMENTAL STUDY IN THE TREATMENT OF GOLD ORES

by

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CHAPTER I. INTRODUCTION

The metallurgical treatment of gold ores has progressed from crude hand methods used by early precious-metal seekers through the well-known smelting, gravity, and amalgamation processes to cyanidation, and more recently to flotation. With present activity in gold mining these processes can all be seen in operation; even today the most primitive methods are employed not far from large, modern metallurgical plants.

In comparing the four processes mentioned for the treatment of gold ores--namely, amalgamation, gravity, cyanidation, and flotation--the latter two are usually the only processes capable of producing satisfactory results when used alone. Although the gravity method is often used efficiently alone in recovering gold from placer deposits, it usually cannot be used effectively for the treatment of vein material unless supplemented by some other process. Amalgamation is usually at a similar disadvantage when treating vein material. The usual comparison between the two processes--cyanidation and flotation--as treatment methods when used alone is that although cyanidation usually yields a higher recovery, the operating cost and first cost of plant is higher than those of flotation. This condition has resulted in large-capacity plants retaining cyanidation and recently constructed small-capacity plants employing flotation. The recent advance in the price of gold, however, has given cyanidation more margin with respect to cost of treatment in competing with flotation, with the result that cyanidation is almost essential at some stage of the process if low-value tailing is to be produced.

The cyanide process was introduced in 1886[1] and remarkable progress was made in its development until about 1915. Since that time little has been accomplished in the way of improving the process itself. Much has been accomplished toward reducing costs and improving recoveries by increasing the mechanical efficiency of the machines used, but since the development of the Pachuca agitator in Mexico prior to 1908 and the countercurrent decantation process by John V. N. Dorr in 1913, no important new practices have been developed.

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1 - Clennell, J. E., The Cyanide Handbook: McGraw-Hill Book Co., pp. 1-32.

The flotation process as applied to gold ores has developed within the last four years and may even yet be said to be in the experimental stage. Research on gold flotation has been carried on continuously at the University of Arizona for the last four years, the work being started by Dr. T. G. Chapman in 1930 and followed successively by D. C. Minton, Jr., in 1930-31, C. E. Evans in 1931-32, and G. D. Gardner in 1932-33.

Although current literature contains an abundant amount of material on both the cyanidation and the flotation processes, it is mainly in the form of descriptions of operating plants rather than descriptions of new innovations in processes. The modern trend is especially well described in an article by William F. Boericke on "Gold Milling Development in Northern Ontario."[2]

It is the purpose of this paper to present results of experimental work on certain innovations of gold-milling methods. These innovations are:

1. The study of a coarse-grinding flow sheet.

2. Cyanidation of ground ore or sands by agitating in a mechanical-agitation flotation machine.

3. Treatment of concentrates from gold ores.

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2 - Boericke, William F., Gold Milling Development in Northern Ontario: Min. and Met., Sept. 1932, pp. 391-400.

CHAPTER II. EXPERIMENTAL STUDY OF A COARSE-GRINDING FLOW SHEET

The flow sheet of treatment proposed for experimental study comprised crushing and grinding to 20-mesh, followed by removal of part of the gold content by roughing on a concentrating table. The table tailing was separated into sand and slime by classifying, after which the sand was treated by cyanidation in percolators and the slime by flotation.

Description of Ore Used

The experimental work on this flow sheet--in fact most of the experimental work described in this paper--was carried out on a sample of gold ore from the Humbug mine, located near Hot Springs Junction, Arizona. The ore is mined principally for its gold and silver contents, but at present minor lead values yield some return. The samples used in these tests contained from 1.38 to 1.69 ounces of gold per ton of ore. A microscopic examination of an embedded table concentrate produced in the laboratory from this ore showed the more important metallic minerals to be native gold, galena, sphalerite, arsenopyrite, chalcopyrite, and pyrite. The relative amount of clean free gold, as indicated by preliminary bottle-amalgamation tests,[3] was small and prohibited the use of the amalgamation process in the treatment of this ore.

Chapman's tests also indicated that cyanidation of the total ore was not feasible due to the excessive consumption of cyanide. His work, however, showed that the ore was amenable to flotation with a recovery of about 90 per cent of the gold when the ore was ground to minus 65-mesh. Although the recovery indicated was high, the value lost in the tailing was approximately $2.00 per ton with gold at $20.67 per ounce. When the price of gold was increased to $35.00 per ounce this loss amounted to about $3.40 per ton. Chapman's work also indicated that a reduction of this loss by finer grinding or the use of special flotation reagents was not feasible. Further study by him revealed that part of the gold lost was contained in a badly slimed mineral which could not be floated. The experimental work on the coarse-grinding flow sheet herein described was intended to improve the recovery of this heavy mineral by removing the non-slimed portion at 20-mesh rather than 65-mesh. Further metallurgical efficiency was expected through relieving the flotation circuit by a preliminary roughing operation and cyanidation of the sand portion of the tailing. The

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3 - Chapman, T. G., private communication of Sept. 20, 1933, "Report on Metallurgical Treatment of Humbug Ore."

excessive cyanide loss was found to be due to cyanicides contained in the slime and it was, therefore, decided to retain flotation for this treatment.

Removal of Coarse Gold from Humbug Ore by Plate Amalgamation

Although, as previously indicated, Chapman's work showed that the coarse gold content of this ore could not be recovered by amalgamation, his work was done on a small scale, using agitation in bottles. It was believed desirable to check this work on a large scale, using plate amalgamation rather than bottles.

Test 1.--A 25-pound sample of ore was ground to minus 48-mesh size and fed by means of a mechanical feeder at the rate of 1 pound per minute over two copper plates painted with silver amalgam, each 8¼ by 30 inches in size and set at a slope of 1.5 inches to the foot. The plates were in series with a vertical drop of one-half inch between them. The results of this test, given in Table 1, showed conclusively that this material was not adapted to amalgamation, as the recovery was only 2.94 per cent of the gold content.

Table 1.—Plate amalgamation of Humbug ore

	Weight, grams	Assay gold, ounces per ton	Weight gold, ounces	Per cent of total gold
Heads............	10,970	1.51	150.54	100.00
Amalgam..........	....	....	4.41	2.94
Tailing..........	10,970	1.46	146.13	97.06

Removal of Coarse Gold from Humbug Ore by a Preliminary Roughing Table Operation

Tests 2 and 3.--Two table tests, numbered 2 and 3, were made to determine the effectiveness of a preliminary roughing table operation. Test 2 was run after grinding to minus 48-mesh and Test 3 after grinding to 20-mesh. It should also be noted that Test 2 was run on the amalgamation tailings of Test 1.

The table used for this work was a 12 by 24 inch laboratory Wilfley table served by a mechanical feeder. The ore was fed to the table at the rate of 1 pound per minute.

The results of Tests 2 and 3 are presented in Tables 2 and 3, respectively.

Table 2.—Table treatment of 48-mesh material preceeded by amalgamation.

	Weight, grams	Tons in 100	Gold assay, ounces per ton	Weight gold, ounces	Per cent of total gold
Heads	10,970	100.00	1.51	150.54	100.0
Amalgam	....	....	....	4.41	2.9
Table concentrate	353	3.22	24.20	77.92	51.8
Table sand tailing	5,317	48.42	0.64	31.05	20.6
Table slime tailing	5,300	48.36	0.77	37.16	24.7

Table 3.—Table treatment of 20-mesh material

	Weight, grams	Tons in 100	Gold assay, ounces per ton	Weight gold, ounces	Per cent of total gold
Heads (20-mesh).............	3,705	100.00	1.69	168.59	100.0
Table concentrate...........	295	7.97	11.10	88.46	52.5
Table tailing...............	3,410	92.03	0.87	80.13	47.5
Table sand tailing..........	3,088	83.35	0.80	66.68	39.5
Table slime tailing.........	322	8.68	1.55	13.45	8.0

Referring to Table 2, it may be noted that the Wilfley table produced a concentrate assaying 24.20 ounces of gold per ton with a concentration ratio of 31 to 1. This concentrate contained 51.8 per cent of the total gold. The sand tailing assayed 0.64 ounce per ton and contained 20.6 per cent of the total gold. The slime tailing contained 24.7 per cent of the total gold and assayed 0.77 ounce per ton.

Referring to Table 3, the concentrate assayed 11.10 ounces per ton and contained 52.5 per cent of the total gold. The tailing assayed 0.87 ounce per ton and contained 47.5 per cent of the total gold. This tailing product was separated into sand and slime products by panning and decanting several times. These products assayed 0.80 and 1.55 ounces per ton and contained 39.5 and 8.0 per cent, respectively, of the total gold. The bulk of the unrecovered gold was in the sands in this test rather than in the slimes, as indicated in Table 2. The segregation of the gold in the sands of Test 3 is explained by the coarser grind which produced only a small amount of slimes. The higher gold content in ounces per ton of the slime product of Test 3 as compared to that of Test 2 can be attributed to the resistance of the gold to sliming as compared to the sliming of the remainder of the ore.

Conclusions

The results of these tests indicate that a preliminary roughing table operation would be of value in the treatment of this ore. The operation would relieve the flotation circuit of approximately one half the gold in the ore and if subsequent treatment of the coarse tailing proves that high metallurgical results could be obtained at this size, additional advantages in increased capacity and decreased costs would result.

CHAPTER III. TREATMENT OF TABLE TAILING OF HUMBUG ORE

The tailing of the rougher table treatment of Humbug ore, described in the preceeding chapter, was separated into sand and slime by means of a small laboratory classifier. The sand was tested for the recovery of its gold content by cyanidation and the slime was tested by cyanidation and flotation.

Cyanidation of Sand and Slime

Chapman's tests, previously referred to, on the cyanidation of the original ore ground to 65-mesh had indicated that about 72.8 per cent of the gold was soluble in cyanide providing a 5-day contact was allowed. The consumptions of lime and cyanide, however, were high and amounted to 10 and 6 pounds per ton of ore, respectively.

One of the causes of high cyanide consumption in most ores is the presence of minerals containing base metals or the oxidized products thereof.[4] A roughing table operation of Humbug ore, such as that described in Chapter II, must

4 - Hamilton, E. M., Manual of Cyanidation: McGraw-Hill Book Co., 1st. ed., p. 12.

necessarily remove appreciable amounts of these base-metal minerals, together with the coarser gold, the latter being but slowly soluble during cyanidation. Furthermore, it was previously determined that the cyanicides in this material concentrated into the slime. From a consideration of the three facts mentioned, it was believed that the deslimed sands of the table tailing would perhaps yield to cyanide treatment more advantageously than either the original ore or the tailing with the contained slime.

In order to test the accuracy of these deductions, tests numbered 4 and 5 were made on sand and slime, respectively. The tests were made in bottles which were rotated continuously for 7 days. The details and results of these tests are presented in Tables 4 and 5, respectively.

Referring to Table 4, it may be noted that 78.5 and 87.5 per cents of the gold were dissolved from the sand in 70 and 168 hour periods, respectively; referring to Table 5, the amounts of gold dissolved in like time periods amounted to 65.0 and 94.8 per cents, respectively. The cyanide consumed by the sands was 3.54 pounds in 168 hours compared to 6.0 pounds per ton for 120 hours, as previously determined for the original ore. The cyanide consumed by the slime was 8.48 pounds per ton of ore for the 168-hour period, which confirmed the work previously done with respect to the concentration of cyanicides into the slime.

Table 4.—Cyanidation of 100-gram sample of minus 20-mesh sand

Time, hours	Total solution, c. c.	Strength of solution, per cent cyanide	Cyanide consumption, pounds per ton	Gold assays, ounces per ton		Gold dissolved, per cent
				Solution	Solids	
Start................	300	0.25	....	....	0.80	....
16..................	290	0.215	2.10	....	....	....
70..................	251	0.208	2.54	0.26	....	78.5
168.................	212	0.191	3.54	0.29	0.10	87.5

Table 5.—Cyanidation of 50-gram sample of slime

Time, hours	Total solution, c. c.	Strength of solution, per cent cyanide	Cyanide consumption, pounds per ton	Gold assays, ounces per ton		Gold dissolved, per cent
				Solutions	Solids	
Start	200	0.2	....	....	1.55	....
16	190	0.125	6.00	....	....	....
70	151	0.104	7.68	0.27	....	65.6
168	112	0.094	8.48	0.39	0.08	94.8

It is interesting to note that considerable gold value still remained undissolved after 168 hours, amounting to 0.10 and 0.08 ounce per ton in the sand and slime residues, respectively.

Effect of Finer Grinding on Cyanidation of Sands

In order to determine the effect of finer grinding, tests, number 6 to 9, were made on the sand product ground to minus 28, 35, 48, and 65 mesh sizes, respectively. Samples were prepared by grinding the 20-mesh sand tailing from the table test in stages and desliming was effected by washing and decanting. Samples of the various sizes were then treated in cyanide solutions for 5 days. The results of these tests are given in Table 6 together with the results of the 20-mesh test for comparison.

The results presented in Table 6 indicate that further grinding of the sand finer than 20-mesh had no appreciable effect in increasing the amount of gold dissolved until the 48-mesh size was reached. In 5 days 94.4 per cent of the gold in the 48-mesh product was dissolved, which yielded a residue containing 0.05 ounce per ton. Cyanide consumption was 3 pounds per ton of ore. Grinding finer than 48-mesh had little effect. The 65-mesh material yielded 95.5 per cent of its gold with a residue which assayed 0.04 ounce per ton and a cyanide consumption of 3 pounds per ton.

Table 6.—Effect of finer grinding on cyanidation of sands

Mesh	Time, days	Cyanide consumption, pounds per ton	Gold assays, ounces per ton		Gold dissolved, per cent
			Heads	Residues	
Minus 20.............	7	3.54	0.80	0.10	87.5
Minus 28.............	5	2.70	0.88	0.10	87.6
Minus 35.............	5	3.15	0.85	0.09	89.4
Minus 48.............	5	3.00	0.89	0.05	94.4
Minus 65.............	5	3.00	0.89	0.04	95.5

Cyanidation of Sands by Percolation

The sands being found amenable to cyanide treatment, the next step involved the treatment of this material in percolators to check the results of the bottle tests and in addition to determine whether or not mechanical difficulties would develop. As previously noted, the 48-mesh material yielded nearly as much of its gold as finer material and enough more than the 20-mesh to warrant further grinding, so a test was run to determine the efficiency of the treatment of the 48-mesh product by percolation.

Test 10.--A 3.2-pound sample of the 48-mesh sand was mixed with 4 pounds of lime per ton of ore and charged to a glass percolator. Cyanide solution was added and allowed to percolate slowly downward for 6 days. Fresh solution was added to replenish the cyanide consumed and that removed in samples. The results of this test are given in Table 7.

The results presented in Table 7 indicate that 79.5 per cent of the gold was dissolved in a 150-hour period. The loss of cyanide for the 150-hour period was 2.27 pounds per ton of ore. No indication of mechanical difficulty developed, although it must be remembered that the column of ore was but 12 inches compared to from 3 to 10 feet normally used in practice.

Table 7.—Cyanidation of 48-mesh sand by percolation

Product	Time, hours	Gold assay, ounces per ton	Gold dissolved, mgs.		Per cent of total gold
			Removed as samples	Total	
Heads........................	....	0.54	....	....	100.0
Solution.....................	6	0.69	2.367	16.567	62.7
	30	0.63	2.161	17.493	66.1
	54	0.59	2.024	18.694	70.7
	126	0.41	1.406	20.341	76.5
	150	0.38	1.303	21.026	79.5
Residue......................	150	0.11	....	....	20.5

Treatment of Slime by Flotation

As indicated in Table 5, the cyanicides not removed in the tabling operation were concentrated in the slime product and, in spite of the fact that 94.8 per cent of the gold content was dissolved, the high cyanide consumption, together with difficulties due to fouling of solutions, did not make the cyanide process attractive for treating this portion of the ore. The finely divided character of this material limited the field of extraction methods to the flotation process, as amalgamation had been shown to be inefficient on this ore and gravity concentration methods were not well adapted to the treatment of slime material.

Test 11.--The slime from the table test was sampled immediately, without drying, allowing only the minimum amount of time for settling, in order to prevent oxidation of the sulphide minerals.

A sample weighing 3.1 pounds was charged to a 2,000-gram capacity Fahrenwald flotation machine with the reagents which follow.

	Pounds per ton of ore
Lime (CaO)	4.0
Amyl xanthate	0.10
Sodium aerofloat	0.10
G. N. S. No. 5 pine oil	0.10

The thick pulp was then conditioned in the machine for 15 minutes. After the addition of sufficient water two 10-minute concentrate products were removed. At the end of the 20-minute period, sodium sulphide was added at the rate of 2 pounds per ton of slime and a third 5-minute concentrate was removed. By means of a La Motte Comparator, the solution was found to have a pH value of 7.8. The results of this test are recorded in Table 8.

Referring to Table 8, the concentrate froths contained 59.4, 12.4, and 5.3 per cents of the total gold, respectively. These three products taken collectively contained 77.1 per cent of the total gold and assayed 7.02 ounces per ton. The tailing assayed 0.20 ounce per ton. The effect of the addition of sodium sulphide was not conclusive, as it was possible that the additional gold recovered in froth No. 3 could have been obtained in the additional time given for this treatment.

Test 12.--A second flotation test was made on the slime product to determine the effect of using an acid rather than an alkaline circuit. The test was carried out in identically the same manner as described for Test 11 with the exceptions that lime was not used and sulphuric acid was added at the rate of 6 pounds per ton of ore at the end of the initial 20-minute period rather than lime, and the sodium sulphide was omitted. The results of this test, as given in

Table 8.—Flotation of slime in an alkaline circuit

Product	Weight in grams	Tons in 100	Gold assay, ounces per ton	Total gold, ounces	Per cent of total gold
Heads	1,413.0	100.00	0.79	79.34	100.00
Concentrate No. 1	65.5	4.64	10.14	47.05	59.4
Concentrate No. 2	22.7	1.60	6.14	9.82	12.4
Concentrate No. 3	34.8	2.46	1.71	4.21	5.3
Tailing	1,290.0	91.30	0.20	18.26	22.9

Table 9, were little different from those obtained in Test 11, a tailing being produced which assayed 0.19 ounce per ton as compared to 0.20 ounce per ton in Test 11. The pH value of the water was 6.8.

Conclusions

The data presented in this chapter, although not conclusive, gives certain indications with respect to the relative merits of coarse and fine grinding flow sheets when treating Humbug ore. In order to study the essential data presented in the detailed tables of this chapter, Tables 10 and 11 have been computed from the detailed data previously given. For purposes of comparison, Table 12, which gives the results of flotation and tabling after fine grinding on Humbug ore, has been supplied by T. G. Chapman.

Referring to Table 12, it may be noted that grinding Humbug ore to 65-mesh followed by flotation and tabling resulted in a recovery of 90.3 per cent of the gold and yielded a tailing which assayed 0.14 ounce of gold per ton.

The results presented in Table 10 indicate that the coarse grinding of the same ore to 20-mesh followed by a roughing table operation with retreatment of table sand and slime tailings by cyanidation and flotation, respectively, resulted in a combined recovery of 93.4 per cent of the gold.

Table 9.—Flotation of slime in an acid circuit

Product	Weight in grams	Tons in 100	Gold assay, ounces per ton	Total gold, ounces	Per cent of total gold
Heads........................	1,308.0	100.00	0.78	78.10	100.00
Concentrate No. 1.............	57.0	4.36	11.52	50.23	64.35
Concentrate No. 2.............	13.5	1.03	5.42	5.57	7.14
Concentrate No. 3.............	10.5	0.80	3.08	2.46	3.15
Tailing......................	1,227.0	93.81	0.19	17.84	25.36

Table 10.—Summary of 20-mesh grinding flow sheet

	Weight, tons	Gold assay, ounces per ton	Per cent of total gold
Heads	100.00	1.69	100.0
Roughing table concentrate (20-mesh)	7.97	11.10	52.5
Cyanide solution, table sands	250.05	0.29	34.7
Flotation, table slimes	....	....	(1) 6.2
Total tailing	....	....	(1) 6.6

(1) Calculated.

Table 11.—Summary of 48-mesh grinding flow sheet

	Weight, tons	Gold assay, ounces per ton	Per cent of total gold
Heads	100.00	1.51	100.0
Roughing table concentrate[1]	6.29	14.35	60.0
Cyanide solution, table sands	140.57	0.09	8.5
Cyanide tailing, table sands	45.35	0.11	6.8
Flotation concentrate, table slimes	4.21	7.02	19.6
Flotation tailing, table slimes	44.15	0.20	5.9

(1) Includes a small amount of gold recovered by amalgamation before tabling.

Table 12.—Summary of 65-mesh grinding flow sheet[1]

	Weight, tons	Gold assay, ounces per ton	Per cent of total gold
Heads	100.00	1.27	100.0
Flotation concentrate	5.76	15.94	72.5
Table concentrate	6.44	3.50	17.8
Tailing	87.80	0.14	9.7

(1) Supplied by Dr. T. G. Chapman.

This comparison indicates that although plant capacity could be increased by the coarser grinding operation metallurgical results would not suffer on account of the coarser grinding. It is true, however, that additional plant cost would be involved in providing the cyanidation equipment necessary for the treatment of the sand table tailing. When the additional plant capacity gained by the coarser grinding operation is compared to the additional cost of cyanide equipment, it is believed that the advantage would be in favor of the coarser grinding, providing the additional plant capacity gained could be utilized to advantage.

Comparing the results of the 48-mesh grinding flow sheet given in Table 11 with those of the 65-mesh flow sheet of Table 12, it may be noted that a higher recovery is obtained with the 65-mesh grinding. This appears to contradict the comparison given for the coarse and fine grinding flow sheets just discussed. When it is considered, however, that grinding to 48-mesh produces more slime than grinding to 20-mesh and when it is further considered that metallurgical results on the slime portion of the table tailing are not as satisfactory as results on the sand portion of the table tailing, the comparisons given in Tables 11 and 12 appear reasonable.

CHAPTER IV. CYANIDATION BY AGITATING IN A MECHANICAL-AGITATION FLOTATION MACHINE

At this stage in the experimental work a method for the treatment of ores by cyanidation was suggested by Mr. W. A. Liddell. The method, for which Mr. Liddell had applied for a patent, consisted of fine grinding of the ore and agitating the ore pulp in cyanide solution in a flotation machine. With the increased agitation and aeration of the pulp obtained in the flotation machine as compared to that in a Dorr or Pachuca agitator, it was believed that the time required for dissolution of the gold would be decreased. Also, the fact that a pulp dilution of 4 or 5 to 1 would be possible, whereas the Pachuca agitator must necessarily operate at a dilution of about 1 1/2 to 1, was considered an advantage in increasing the rate of dissolution.

At the Wright-Hargreaves pilot plant where a new type of "Super-agitator" had been installed, it had been found that agitating with low-pressure air from a blower was not enough; the air must be dissolved, and in order to accomplish this it must be beaten into the pulp.[5]

The Fahrenwald machine was the only small-scale flotation machine in the University of Arizona metallurgical

5 - Boericke, W. F., Gold Milling Development in Northern Ontario: Min. and Met., Sept. 1932, p. 393.

laboratories suitable for this work. The materials of construction of all pneumatic machines in these laboratories were not suitable for cyanide work. It was, therefore, decided to use the Fahrenwald machine for these tests.

Test 13.--A sample of ore from the Creston Mine in Sonora, Mexico, was selected for the preliminary tests, as this material had been tested previously by cyanidation and was known to yield a high percentage of its gold content by this method. Creston ore, described by Minton,[6] had been found by Chapman to yield 94.1 per cent of its gold by cyanidation when ground to minus 100-mesh. A test was made, using 1,500 grams of this ore ground to minus 20-mesh size. The sample was mixed with 2.5 pounds of lime per ton of ore and placed in a Fahrenwald laboratory flotation machine with 6,000 c. c. of 0.20 per cent cyanide solution, which provided a pulp dilution of four parts liquid to one of solids.

The pulp was then agitated continuously for 90 minutes at somewhat slower speed than that used in a flotation test. Samples were removed every 15 minutes for the duration of the test to be assayed for cyanide consumption and gold recovery. The detailed results are given in Table 13.

The recovery of the gold, as shown in Table 13, was 67.4 per cent in 90 minutes. The tailing assayed 0.18 ounce per ton as compared to 0.55 ounce in the original ore. Cyanide consumption was 1 pound per ton of ore as compared

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6 - Minton, D. C., Jr., Metallurgical Treatment of Gold Ores: Library, University of Arizona.

Table 13.—Cyanidation by agitating 20-mesh Creston ore

Sample number	Time, minutes	Cyanide consumption, pounds per ton of ore	Gold assay, mgs.	Gold in samples, mgs.	Gold dissolved, mgs.	Per cent of total gold
Heads............	....	....	(1) 0.55	....	....	100.00
1................	15	0.30	(2) 0.09	0.18	10.80	37.9
2................	30	0.46	0.11	0.40	13.38	47.0
3................	45	0.83	0.12	0.64	14.80	52.0
4................	60	0.89	0.13	0.90	16.24	57.1
5................	75	0.99	0.14	1.18	17.70	62.2
6................	90	1.00	0.15	1.48	19.18	67.4
Tailing..........	....	....	(1) 0.18	....	....	32.6

(1) Ounces per ton.

(2) Gold content in 50 c. c. reported for all solution.

to a consumption of 2.5 pounds indicated in Chapman's tests.

Effect of Materials of Construction on Agitation.--The importance of using a machine with no brass parts for these tests was brought out when a preliminary 500-gram test was made, using a sample of the same ore and carried out in identically the same manner in a smaller machine which was found to have a brass impellor housing. The cyanide consumption in this latter test was 11.4 pounds per ton as compared to 1 pound in Test 13 which was conducted in a machine without brass parts.

Test 14.--In order to determine the adaptability of this process to the treatment of the sand product of the Humbug ore, a similar test was made on a 3.65-pound sample of the minus 48-mesh sand tailing from Test 2. The tailing was mixed with 2 pounds of lime per ton and charged to the machine used in Test 13 with 0.15 per cent cyanide solution added in sufficient quantity to provide a pulp dilution of 4 to 1. The tabulated results in Table 14 indicate a maximum solubility of 72.5 per cent of the gold in 75 minutes. The tailing assayed 0.15 ounce per ton. Cyanide consumption amounted to 2.17 pounds per ton of ore as compared to 3 pounds per ton in Test 11, the latter test being conducted by standard cyanidation methods.

Table 14.—Cyanidation by agitating Humbug sand tailing

Time in minutes	Cyanide consumption, pounds per ton	Gold assay, mgs.	Gold in samples, mgs.	Gold dissolved, mgs.	Per cent of total gold
Heads............	....	(1) 0.51	....	....	100.0
15..............	0.60	(2) 0.05	0.172	11.388	36.7
30..............	0.98	0.08	0.446	18.117	58.4
45..............	1.19	0.09	0.7546	20.326	65.6
60..............	1.40	0.09	1.063	20.326	65.6
75..............	1.96	0.10	1.406	22.466	72.5
90..............	2.17	0.10	1.749	22.466	72.5
Tailing..........	....	(1) 0.15	....	....	27.5

(1) Ounces per ton.

(2) Gold content in 50 c. c. reported for all solution.

Test 15.--A third test was made using an Arizona gold ore which assayed 1.71 ounces of gold per ton. A sample weighing 335 grams was ground to minus 100-mesh, mixed with 2.5 pounds of lime per ton of ore and charged to a 500-gram capacity Fahrenwald flotation machine with a pulp dilution of 4 to 1, as in the previous tests, and a cyanide strength of 0.15 per cent. The test was then carried out as described for Test 14; the results are given in Table 15.

Table 15 indicates that 66.7 per cent of the gold was dissolved in 60 minutes and 67.8 per cent in 90 minutes, yielding a tailing which assayed 0.55 ounce, containing 32.3 per cent of the gold. The high cyanide consumption, 12.2 pounds per ton, was due to the brass parts contained in the small Fahrenwald machine. A blank run in this machine with no ore present, using only 0.15 per cent cyanide solution, indicated that the materials of construction in the machine accounted for 10.2 pounds of the 12.2 pounds consumed in Test 15. This result in turn indicated that a consumption of about 2 pounds per ton was due to the ore present in Test 15.

Conclusions

The data presented in this chapter indicate that the speed of dissolution of gold in a cyanide solution when employing a mechanical-type flotation machine is rapid.

Table 15.—Cyanidation by agitating an Arizona gold ore ground to 100-mesh

Sample number	Time, minutes	Cyanide consumption, pounds per ton	Gold assay, mgs.	Gold in samples,	Gold dissolved, mgs.	Per cent of total gold
Heads..........	....	....	(1) 1.71	....	....	100.0
1..............	15	5.37	(2) 0.29	0.58	8.352	42.5
2..............	30	5.90	0.36	1.30	10.948	55.8
3..............	45	9.25	0.38	2.06	12.244	62.2
4..............	60	10.69	0.38	2.82	13.104	66.7
5..............	75	11.47	0.36	3.54	13.188	67.1
6..............	90	12.19	0.34	4.22	13.332	67.8
Tailing........	....	....	(1) 0.55	....	....	32.2

(1) Ounces per ton.

(2) Gold content in 50 c. c. reported for all solution.

Although no comparative data are presented to compare this speed with the speed of dissolution when standard agitators of the Dorr and Pachuca types are employed, it is believed from past experience with these standard agitators that the speed when using a mechanical-type flotation machine is greater.

It was intended to try the matless pneumatic machine, which receives air from a low-pressure blower, for the purpose of determining whether or not it was essential to beat the air into the pulp to obtain the speed of dissolution, as was done when the mechanical-type flotation machine was employed. As previously mentioned, suitable equipment was not available for this comparison.

With respect to the consumption of cyanide, the data presented indicate that when the materials of construction of the flotation machine are suitable for cyanide pulps, the consumption of cyanide is lower for the excess aeration method than for standard cyanide methods.

CHAPTER V. TREATMENT OF CONCENTRATES PRODUCED FROM GOLD ORES BY CYANIDATION

The treatment of concentrates from gold ores often presents a difficult problem; in fact, many such products cannot be treated effectively for the recovery of gold except by a smelting process. The pyro-metallurgical treatment of such products presents a problem beyond the scope of this paper, but with conditions as they are today the importance of this method cannot be overlooked. Although this method of treatment has been unattractive when operated in small-scale plants in the past, the increase in the price of gold has changed the situation so that it is not at all certain whether the older viewpoint holds today.

The only other known methods of treatment that produce gold bullion as a final product from these concentrates are amalgamation, cyanidation, and chlorination. The last-mentioned process was used considerably some years ago, especially in California, for the treatment of pyritic concentrates,[7] but the high cost of this method does not make it appear attractive at present.

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7 - Austin, L. S., The Metallurgy of the Common Metals: John Wiley and Sons, Inc., 6th ed., p. 144.

Test 16.--It was suspected that since amalgamation had been so ineffective in treating the original Humbug ore little improvement could be expected in amalgamating the same gold in the concentrate. However, in order to confirm this view, a test was made on 1,000 grams of moist, table concentrate assaying 15.40 ounces of gold per ton from the Humbug concentrator. The concentrate pulp, comprising 5 per cent of mercury, 0.4 per cent of sodium hydroxide, and 70 per cent of solids, was mixed in a rotating bottle for 6 hours. The results of this test indicated that 10.9 per cent of the gold was amalgamated; the residue assayed 13.72 ounces of gold per ton. These results confirmed previous work and disposed of the amalgamation method.

As previously stated, these concentrates carried the bulk of the base-metal minerals in the ore and would be expected to consume a large amount of cyanide, if they were amenable to such a treatment at all. When it is considered, however, that a high cyanide consumption per ton of concentrate would not necessarily mean a prohibitive consumption per ton of original ore, it was decided to test the concentrate for solubility of the gold by cyanidation.

Test 17.--A cyanidation bottle-test was made using 100 grams of concentrate, 9 pounds of lime per ton, and 300 c. c. of 0.2 per cent cyanide solution. The bottle was rotated for 48 hours.

The results of this test indicated that 80.6 per cent of the total gold was dissolved, yielding a tailing which assayed 2.66 ounces per ton as compared to 13.73 ounces in the original product. The lime and cyanide consumptions were 8.8 and 10.8 pounds, respectively.

Test 18.--In following indications from Test 17 that a fair recovery could be made by cyanidation, a second test was made to determine the adaptability of the material to cyanidation by the percolation method. A 1,500-gram sample was mixed with 9 pounds of lime per ton and placed in a glass percolator; 700 c. c. of 0.20 per cent cyanide solution were allowed to percolate downward for 20 hours until drained. The charge was then allowed to stand for 4 hours for aeration, after which the drained solution was returned to the charge and the cycle repeated. At the end of each 24-hour period a sample of solution was removed and fresh solution added to replenish the sodium cyanide consumed. The results of this test are given in Table 16.

Referring to Table 16, the gold dissolved in 248 hours amounted to 51.4 per cent of the total; the consumption of cyanide was 11.8 pounds per ton. However, it will be noted that the recovery at the end of 147 hours had dropped below that of 123 hours, which was accounted for by reprecipitation of the gold when the solution became fouled. In order to obtain some data to explain the cause of the apparent fouling

Table 16.—Cyanide percolation treatment of Humbug concentrate

Time, hours	Cyanide consumption, pounds per ton	Gold assay, mgs.	Gold in samples, mgs.	Gold dissolved, mgs.	Per cent of total gold
Heads..............	....	(1) 13.96	....	....	100.0
48-hr. solution......	9.83	(2) 19.24	38.48	269.36	37.4
72-hr. solution......	10.35	20.13	78.74	320.30	44.5
96-hr. solution......	10.76	17.49	113.72	323.54	45.1
123-hr. solution.....	10.87	15.05	144.24	324.42	45.2
147-hr. solution.....	11.25	12.53	169.30	319.66	44.5
175-hr. solution.....	11.50	11.56	192.42	331.14	46.2
200-hr. solution.....	11.70	10.61	213.64	350.96	48.9
248-hr. solution.....	11.81	11.11	235.86	369.18	51.4
Tailing.............	....	(1) 6.78	....	....	48.6

(1) Ounces per ton.

(2) Gold content in 50 c. c. reported for all solutions.

of the solution, a partial qualitative analysis was made of a sample of solution. The metallic elements found to be present were copper, iron, lead, zinc, gold, and silver. A test for sulphur as sulphate or thiocyanate proved negative.

Test 19.--Test 19 was made with the idea of preventing excessive fouling of solution by removing the solution after 24 hours of contact and, instead of recirculating the solution removed, adding fresh solution and repeating the cycle each 24-hour period for 5 days. The residue of Test 18 was used as heads to Test 19. The results of Test 19 are presented in Table 17.

Referring to Table 17, the results indicate that 46.7 per cent of the gold was dissolved from the residue of Test 18 by employing fresh solutions at 24-hour periods. The loss of cyanide amounted to 4.2 pounds per ton. Combining the gold dissolved in Test 18 with that of Test 19, the total gold dissolved from the concentrate amounted to 76.6 per cent and the total loss of cyanide was 16.0 pounds per ton.

Conclusions

The results of tests described in this chapter indicate the following conclusions:

1. The gold in Humbug concentrate cannot be recovered by amalgamation methods.

Table 17.—Cyanidation of Humbug concentrate with fresh solution

Time, hours	Cyanide consumption, pounds per ton	Gold assay, mgs.	Gold in samples, mgs.	Gold dissolved, mgs.	Per cent of total gold
Start.............	....	(1) 6.78	....	....	100.0
24-hr. solution....	1.5	(2) 2.85	5.70	28.50	12.2
48-hr. solution....	1.6	3.85	13.40	44.20	19.0
72-hr. solution....	2.3	4.07	21.54	54.10	23.2
96-hr. solution....	2.6	7.06	35.66	92.14	39.6
120-hr. solution...	3.8	3.38	45.68	99.24	41.4
144-hr. solution...	4.2	1.97	108.57	108.57	46.7
Tailing...........	....	(1) 3.26	....	....	53.3

(1) Ounces per ton.

(2) Gold content in 50 c. c. reported for all solutions.

2. Although the combined gold dissolved by cyanide in Tests 18 and 19 amounted to 76.6 per cent of the total gold, the results are not conclusive, since Test 18 was performed under different conditions as compared to Test 19. The only indication obtained as far as the cyanide method is concerned is that under certain conditions the major portion of the gold is soluble. Considerable more work would be required to obtain data which would be considered conclusive.

3. The cyanide consumption, although amounting to 16 pounds per ton of concentrate, amounts to less than 1.0 pound per ton of concentrator feed and is, therefore, not considered excessive.

CHAPTER VI. SUMMARY OF CONCLUSIONS

Conclusions relating to the main subdivisions of the experimental work reported in this paper have been given at the end of each chapter.

Conclusions for the removal of gold by a roughing table operation may be found on page 11; those applying to a comparison of different degrees of grinding and different flow sheets based on the degree of grinding are presented on page 23; conclusions with respect to the Liddell method of cyanidation are given on page 34; and conclusions with respect to the cyanidation of flotation concentrate are given on page 41.