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Recovery of carbonate copper ore by means of flotation at the Kennecott Copper Corporation plant, Kennecott, Alaska

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RECOVERY OF CARBONATE COPPER ORE BY MEANS OF FLOTATION

AT THE

KENNECOTT COPPER CORPORATION PLANT
KENNECOTT, ALASKA.

BY

GEORGE LEO RICHERT

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A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

Engineer of Mines

Matahambre, Pinar del Rio, Cuba

1926.

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Approved by C.R. Forbes
Professor of Mining.

Thesis: Recovery of carbonate copper ore
by means of flotation at the Kennecott
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INTRODUCTION

The Kennecott Copper Corporation mines and the adjoining Mother Lode Coalition Co. mine, which the Kennecott Copper Corporation controls and operates as an integral part of their Kennecott, Alaska camp, are situated in the Nizina Mining District, 196 miles inland from Cordova, Alaska, the tide-water shipping point.

The first claims were discovered in 1900, and these later became the property of the Kennecott Copper Corporation. The Kennecott holdings consist of 111 mineral claims and the Mother Lode Coalition Co. has 73 claims.

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GEOLOGY AND ORE DEPOSITS AT KENNECOTT, ALASKA.

As the composition of the gangue rock has a great deal of influence on the action and behavior of the oils and reagents used in the flotation plant at Kennecott, there follows a brief synopsis of the geology and a description of the ore deposits found at the Kennecott mines.

The formations found at and in the vicinity of Kennecott, are as follows:-

Quaternary -

Alluvium: flood plain gravels, sand and silts.
Rock Glaciers: broken rock and ice.
Moraines: glacial till, partly sorted.

Jurassic or later -

Quartz diorite porphry: stocks, sills and dikes.

Upper Jurassic -

Kennecott formation: shales, sandstone and conglomerates.

Upper Triassic -

McCarthy shale: shale with thin bedded limestones.
Chististone Limestone: massive limestone (the ore containing bed).

Triassic -

Nikolai greenstone: altered basaltic lava flows.

The Chististone limestone, which is the ore-bearing formation, overlies the Nikolai greenstone and has an estimated thickness of 3,500 feet. It is a massive formation, intersected by numerous faults and fracture systems. The lower part of the formation consists of a 7-ft. bed of shale; above the shale is 12-ft. thin-bedded rough limestone, locally known as "Crinkley lime". Above this 30 feet of dull grey limestone. Above this are massive beds of sparkling light-grey dolomitic limestone and dolomite. Some of the dolomitic limestone and the dolomites have no physical differences discernible to the eye, and their classification can only be determined by analyzing and determining the amount of magnesium present.

The Kennecott ore bodies are replacement deposits in limestone with chalcocite the predominating mineral in the deposits. Following chalcocite in range of importance and amount come the carbonates azurite and malacite, then covelite and a very small amount of enargite.

The ore bodies are found along fissures that apparently start from the greenstone contact. The mineralization along the fissures is much less as the fissure passes into the dull-grey limestone and rarely is ore found in this formation or in the "Crinkley lime" formation. Accompanying and usually intermingled with the mineralized area along the fissures are stringers and veins of calcite.

From this synopsis of the description of the geology and ore bodies it is seen that the gangue rock accompanying the ore to the flotation plant is high in calcium and magnesium. The presence of the calcium and magnesium beyond doubt has some effect on the action of the reagents and oils used in the flotation plant. While the exact effect produced has never been determined, similar plants elsewhere have not proven successes.

MILL EQUIPMENT AND OPERATION

The term "mill" will be used in this paper to denote that part of the Kennecott plant concentrating by mechanical means only, the "flotation" and "leaching" plants are housed and operated separately.

The following general outline of the milling proceedure at Kennecott will give some idea as to the amount, size and shape of the flotation plant feed.

The mill equipment, at the time the flotation plant started operating, consisted of the following:

Buchanan Jaw Crushers
Trommels
Symons Crusher
Trommels
Bull Jigs
Drag Dewaterer
Traylor Rolls
Trommels
Hancock Jigs
Single Hutch Hartz Jigs
Colorado Impact Screen
Traylor Rolls
Hancock Jigs
2 compartment Hartz Jigs
Drag Dewaterer
Richard's Classifier
Wilfley Tables
Chip Trommel
Wilfley Tables
Plato Tables
Callow Cones
James Tables
Dorr Thickeners
Plato Slime Tables
James Slime Tables

The final mill tailing is composed of the cobbined tails of the first and second Hancock Jigs, the second Wilfley tables, the Plato Tables, the first James Tables and the James Slime Tables.

It will be noted that there was no ball mill crushing, though very recently ball mills have been added to crush sand and slime table tails so that they may be sent direct to the flotation plant.

The total mill tails were sent to two Esperanza Drag Classifiers. The coarse material brought out by the drags became the Ammonia Leaching Plant feed and the overflow from these classifiers became the Flotation Plant feed.

SCREEN TEST REPORT

Mill Tails Composite - March 10-20, 1924.

Screen	% Weight		Assays		Contents		% Total Contents	
	Direct	Cum.	Total Cu.	Carb. Cu.	Total Cu.	Carb. Cu.	Total Cu.	Carb. Cu.
On - 6 M.M.	30.2	30.2	0.75	0.51	.226	.154	16.1	14.1
2 M.M.	28.6	58.8	1.26	0.89	.361	.255	25.7	23.4
20 Mesh	9.5	68.3	1.14	0.93	.108	.088	7.7	8.0
65 "	15.2	83.5	1.72	1.44	.261	.219	18.5	20.1
200 "	7.8	91.3	1.56	1.40	.121	.109	8.6	10.1
Thru 200 "	8.7	100.0	3.73	3.03	.325	.264	23.4	24.3
TOTAL AVERAGES					1.402	1.089	100.0	100.0

Remarks:

Head Sample
% Cu. equals 1.42
% Carb. Cu. " 1.07

RECOVERY OF SULPHIDE AND CARBONATE ORE BEFORE THE USE OF FLOTATION.

Generally speaking the recovery of the sulphides by the mill was entirely satisfactory though a higher recovery is always to be desired. However, due to the low specific gravity of the carbonates, at least compared to the sulphides, the mill and leaching plant did not make a satisfactory carbonate recovery. To illustrate, a summary of the mill operation for the year 1922, before the flotation plant was put into operation, follows:

Average mill heads assay, total copper	6.56%
As sulphides	4.16%
As carbonates	2.40%

Concentrates produced assay total copper	48.95%
As sulphides	35.93%
As carbonates	13.02%

Tails assay, total copper	1.55%
As sulphides	0.41%
As carbonates	1.14%

Recovery, total copper	78.88%
Recovery of sulphides	91.20%
Recovery of carbonates	57.44%

While improvements in the mill raised the recovery somewhat between January 1, 1923 and May, 1923, when the flotation plant was put into operation, these figures clearly show the inability of the mill to hold the carbonates and the need for some means to recover them.

Following the mill the tailings were sent to the Ammonia Leaching Plant. This process of ammonia leaching with steam under pressure was developed and patented by Mr. E. T. Stannard, now Vice-President of the Kennecott Copper Corporation, for the purpose of recovering the carbonate ore in the mill tails. However, as the leaching is done with ammonia and steam under pressure, the fines, though most of the fines were discarded before the flotation plant began operation, tended to cake and crust and so prevented a good circulation of the ammonia liquor. While the leaching plant recovery boosted the total carbonate recovery of the mill, as stated previously, for the year 1922, from 57.44% to 80.47% total for all operations, the final recovery was still far from satisfactory. Moreover, while the leaching plant is a commercial success, compared to discarding the total mill tails, the high cost of operation due to the camps remoteness from the centers of distribution, the high cost of the equipment used, especially the aluminum stills, left a need for further improvements and especially for an improvement that would give the leaching plant clean coarse feed.

With these ideas in mind, after exhaustive tests and experiments the Flotation Plant was designed, built and in May, 1923, put into operation.

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PROPORTION OF CARBONATE ORE TO SULPHIDE ORE IN THE MILL AND FLOTATION FEED.

Before going into details of the mechanical operation of the flotation plant some idea of the character of the mill and flotation feed might prove interesting.

The mill feed at Kennecott varied not only in copper content, which was usually more or less uniform for a day's run, but also in the proportion of carbonate ore to the sulphide ore. As the mill feed consisted of ore from four, and for two months during the summer five mines, trying to control the sulphide, carbonate proportions were practically an impossibility. As the flotation plant was primarily intended to recover the carbonates from the mill tail fines and slimes, this fluctuation in the percentage of carbonates in the feed necessitated constant watching, changing and regulation of the oils and reagents. Because it will probably be impossible to ever have a fixed flotation feed, at least as far as the proportion of sulphides to carbonates is concerned, successful operation of the plant will always be more or less a matter of having careful, interested operators in charge.

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FLOTATION PLANT EQUIPMENT

A summary of the flotation plant equipment, in the order in which the feed passes through following the overflow of the Esperanza Drag Classifiers, is as follows:

2 - 1 Tray Dorr thickeners 20' diameter,

1 - Standard Janney Cell 24" (as an emulsifier),

1 - Bucket elevator - 10",

1 - Centrifugal pump 2" (use optional with the above mentioned bucket elevator),

6 - Standard Janney Cells 24",

1 - Bucket elevator 10",

1 - Dorr thickener 18' diameter (for concentrates, use optional, depending on dryness of froth taken off),

1 - Oliver filter 4' x 8' diameter,

1 - Automatic tailings sampler.

In addition there is a laboratory containing a small Janney cell (laboratory model), crushers, hot plates, drying ovens, oils, acids, reagents, etc.

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REAGENTS AND OILS USED IN THE FLOTATION PROCESS.

In the laboratory tests preliminary to the starting of operation in the flotation plant, all, or nearly all standard flotation oils and reagents then on the market were tried, as well as the by-product reagents sold by the large rubber companies. At the time the flotation plant started operating, good results had been obtained in the laboratory, and the results were better in actual operation of the plant by the use of a sodium sulphide solution, accompanied by a sulphur-lime solution, together with G.N.S.#4 pine oil (1 lb. per ton of feed) and a 50:50 mixture of Barrett #4 and #634 (2 lbs. per ton).

Nearly as good results were obtained with the above mentioned sodium sulphide and sulphur-lime solutions and G.N.S.#4 pine oil together with #80 Pensecola Tar and Turpentine oil, also by using steam distilled pine oil instead of the G.N.S.#4 pine oil.

The sodium sulphide and the sulphur-lime solutions were prepared and added with the idea in mind of giving the carbonate ore bearing particles in the feed a sulphide coating so that they would be acted upon by the "floating" oils and held by the "frothers", the same as the sulphide ore bearing particles. Demonstration proved that this was actually accomplished and the particles containing carbonates reacted to the flotation process much the same as the sulphide ores.

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OPERATION OF THE FLOTATION PLANT.

In the plant operation the oils were added from buckets to which small faucets had been attached. The oil was fed into the feed launder, the amount being regulated by the faucet. The sodium sulphide (commercial 35 to 40% Na_2S), which was usually caked when received, was broken up with a hammer, put into a small tank with a steam line attached, water added, then steamed and boiled for about three hours or until the sodium sulphide was dissolved. The solution, a deep orange-red color, was then allowed to cool. After cooling it was fed into the feed launder by means of a small pipe with a valve attached. This makeshift feeder gave trouble due to the pipe corroding and was replaced by a small wheel and bucket feeder. The amount of sodium sulphide used in preparing this solution ranged from 4 lbs. to 5 lbs. per ton of dry feed passing through the flotation plant. The sulphur, commercial lump, and lime, equal parts and averaging about 0.8 lb. per ton of dry feed was prepared as follows: The lime, as a rule this had become "slaked" due to exposure, was placed in a small tank with steam pipe connection, the tank partly filled with water and the sulphur added.

Much trouble was experienced with the sulphur collecting at the bottom, forming a hard layer or lumps and not completely dissolving. To remedy this the sulphur was placed in a fine mesh wire basket, the basket suspended in the lime solution and the whole allowed to boil until the resulting solution was a good "lemon yellow" color. Even this mixing process was not satisfactory, as the sulphur tended to form a gum, would not dissolve entirely and a true lime-sulphur solution was not obtained. However, the solution as it was seemed essential to the plants' operation and until the summer of 1924 the lime-sulphur solution was made in this manner. At this time Bulletin #1285, issued by the U.S. Department of Agriculture came to the metallurgist's attention. In this bulletin the preparation of a sulphur-lime solution for spraying fruit trees is described. The bulletin advised the use of unslaked lime, the heat generated by the slaking helping to make the dissolution of the sulphur complete. The bulletin also advised the use of commercial ground, lump free sulphur, which is made into a paste by the addition of water before it is added to the lime solution, where it is boiled 50 minutes. This scheme or process was adopted almost entirely as given in the bulletin, flowers of sulphur or the equivalent being used instead of the commercial product and all with very good results. Following this change in the preparation of the lime-sulphur solution, the grade of the concentrate rose from around 20% Cu. to well above 30% and as high as 36% being obtained. Secondly the lime in the sulphur-lime solution apparently had some effect on the working of the Oliver filter. Previous to the change in making this solution the concentrate was at times "gummy" and "sticky", retarding the action of the filter. Following the change, however, the concentrate was easily handled and thoroughly dried. To the writer's knowledge, however, up to this time there had been no analysis made to determine the alkalinity of the sulphur-lime solution, or of the feed itself, though the fact that the presence of lime influenced the results obtained in the flotation plant cells as well as the action of the Oliver filter was recognized.

The feed to the flotation plant coming from the overflow of the Esperanza Drag Classifiers and averaging about 65 dry tons in 24 hours, passed through two Dorr tank thickeners came into the cell feed launder at a 4.50 to 1 water to solid ratio. The feed to the cells would all pass 80 mesh and averaging about 16% on and through 200 mesh. Average assay of the flotation feed was 3.75% total copper and 2.85% carbonate copper. To the feed while passing through this launder was added the sodium sulphide solution, the sulphur-lime solution, frothing oils and floating oils. The feed then followed through one of three routes or lines. Each of these three lines for the feed were tried out on long runs with much the same final results although the third route was finally accepted as the best one.

In the first route the first cell was used as an emulsifier, no froth being taken off. Following the emulsifier the feed passed through the remaining cells with most of the concentrate froth being taken off before the last cell was reached. At the last cell part of the remaining feed, that passing through an overflow valve, was returned to the primary feed launder to go through the circuit again. The sending of part of the feed from the last cell back into the primary feed launder applies to the second and third routes as well as to the first.

In the second route there was no emulsifying cell and concentrate froth was taken from all the cells but the last. This froth was then sent to the last cell which was used as a cleaner cell.

In the third route only a very small amount of froth was taken from the first cell, more from the second, etc., the amount increasing at each cell in the series. In this last route, the adopted one, the first cell was considered a partial emulsifier as only a very small amount of froth was taken off, most of the concentrate coming from the last cell. The third route also differed from the others in that a small amount of floating oil was added to the third and fourth cell.

For some time after the plant was put into operation following the series of cells, the final concentrate froth was sent to a small Dorr Thickener and then to the Oliver Filter. Later, however, with equally good or even better results, the concentrate froth was sent direct to the filter.

The flotation plant concentrate taken from the filter was shoveled from a bin into sacks. The sacks were elevated to a loading shed by means of a belt and arm elevator. The sacked concentrates, under cover, were piled up until a sufficient quantity was on hand, then they were loaded into box cars for shipment.

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KENNECOTT COPPER CORPORATION

KENNECOTT, ALASKA

DAILY REPORT OF FLOTATION OPERATION

Date May-30, 1924

METALLURGICAL

Estimated y Tons Treated		Heads—% Copper				Calc. Concts.—% Copper				Tailings—% Copper				Calc. Recovery			
		Today		To Date		Today		To Date		Today		To Date		Today		To Date	
day	To Date	Total	Carb.	Total	Carb.	Total	Carb.	Total	Carb.	Total	Carb.	Total	Carb.	Total	Carb.	Total	Carb.
4	1928	3.33	2.81	3.78	3.20	18.3	16.0	22.6	18.5	.87	.73	1.32	1.19	77.6	77.6	69.2	67.2

SULFIDIZING REAGENTS

Sodium Sulfide				Sulfur				Lime				Total				Coppers
mount		Lbs. per Ton		Amount		Lbs. per Ton		Amount		Lbs. per Ton		Amount		Lbs. per Ton		Amt #per Ton
y	To Date	Today	To Date	Today	To Date	Today	To Date	Today	To Date	Today	To Date	Today	To Date	Today	To Date	Day Date Day Date
0	9356	4.1	5.0	—	915	—	0.4	—	870	—	0.4	350	12071	5.5	6.3	90-930-14-.05

OILS

GNS #4				Barrett #4-634				Pens #80				S.S. Pine				Total			
mount		Lbs. per Ton		Amount		Lbs. per Ton		Amount		Lbs. per Ton		Amount		Lbs. per Ton		Amount		Lbs. per Ton	
y	To Date	Today	To Date	Today	To Date	Today	To Date	Today	To Date	Today	To Date	Today	To Date	Today	To Date	Today	To Date	Today	To Date
	1856	1.0	1.0	140	3884	2.2	2.0	20	401	.3	.2	—	18	—	—	226	6159	3.5	3.2

DELAYS

lay	To Date	% Running Time to Date	Causes
-	6.6	99.2	

MISCELLANEOUS

Ratio ater: Solids		
ay	To Date	
6	4.4	

SCREEN TEST REPORT

FLOTATION TAILS COMPOSITE - DEC. 11-21, 1923.

Screen	% Weight		Assays		Contents		%Total Cont.	
	Direct -	Cum.	Total Cu.	Carb.Cu.	Total Cu.	Carb.Cu.	Tot.Cu.	Carb. Cu.
On 100 Mesh	4.0	4.0	2.15	1.78	.086	.076	4.97	4.73
150 "	5.0	9.0	1.39	1.13	.070	.057	4.05	3.54
200 "	11.0	20.0	1.13	1.05	.124	.115	7.18	7.15
Thru200 "	80.0	100.0	1.81	1.70	1.446	1.360	83.80	84.58
Total Averages					1.726	1.608	100.0	100.0

Remarks:

% Cu. equals 1.70

% Carb. " 1.60

EFFECT OF SLIMES ON FLOTATION

The effect of slimes upon the operation of the flotation plant is interesting. While slime is the "bugaboo" of all flotation plants Kennecott had an extraordinary amount to contend with part of each year, due to the lack of fresh water. The effect of the slimes showing in both the grade and amount of concentrate produced, and in the amount of feed lost at the overflow of the Dorr thickeners.

The water supply at Kennecott depended solely on the melting snows and glacial streams from the mountains behind the camp. During an ordinary winter this supply is ample until about the first of February. From February until the latter part of April the supply of glacial water is practically nothing. Consequently the water in the plants is used over and over, returning after each circuit through the different plants to a spray pond where it is cooled and partially cleaned by allowing the sediment to settle. Also despite close watching, some grease and oil will get into the water which is impossible to take out.

The effect of the dirty water was immediately felt in the flotation plant. The quantity of feed in the slimes over-flowing from the Dorr thickeners inrreased, the recovery went down and consequently the percentage of copper in the tails increased while the grade and quantity of concentrate produced decreased.

Knowing the results of increased slimes, dispersion tests were taken on samples of the flotation tails every three days throughout the year. In making these tests 10 c.c. of a 10% solution of sodium silicate was added to two-thirds of a bucket of pulp. After standing seven minutes, to allow the sands to settle, the slimes were syphoned off. Then both sands and slimes were dried, weighed and assayed. The percent of sands and slimes was calculated and the assay obtained from them checked against the shift tailing assay. There was usually some discrepancy between the dispersion test assays and the shift assays, but this might be expected as the dispersion tests were run on single grab samples while the shift assay was run from an eight hour sample cut by an automatic sampler.

After numerous laboratory experiments it was found that the addition of a copperas (ferrous sulphate) solution to a sample of the feed in which the slimes would not readily settle caused the slimes to settle down almost as fast as the sands. Consequently a solution of copperas, about one and a half pounds per ton of dry feed through the flotation plant, was prepared and fed into the feed launder leading to the Dorr thickeners. This solution apparently had little or no effect upon the action of the oils and reagents but produced an almost clear overflow from the Dorr thickeners, resulting in increased tonnage and higher recovery.

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DISPERSION TESTS AND FLOTATION RESULTS

Sept. 1923 - Jan. 1924

	SAND		SLIME		TOTAL	RECOVERY	CONC.
	% Wt.	% Cu.	% Wt.	% Cu.	% Cu.		% Cu.
Sept.	73.8	0.38	26.2	2.81	0.99	79.4	22.5
Oct.	76.1	0.39	23.9	2.43	0.86	79.1	24.7
Nov.	75.9	0.81	24.1	2.44	1.21	79.6	29.8
Dec.	71.8	0.74	28.2	2.63	1.25	75.7	29.1
Jan.	64.3	0.86	35.7	2.89	1.40	73.7	28.1

DISPERSION TESTS ON FLOTATION TAILINGS

FEBRUARY 1924

DATE	SANDS			SLIMES			CALC. ASSAY		SHIFT ASSAY	
	% Wt.	% Cu.	%Carb.	%Wt.	%Cu.	% Carb.	%Cu.	% Carb.	%Cu.	% Carb.
Feb. 4	72.0	1.95	1.80	28.0	5.17	4.22	2.85	2.48	2.14	1.82
6	74.7	.31	.26	25.3	3.30	2.40	1.07	.80	1.52	1.30
8	64.3	.60	.49	35.7	3.63	3.14	1.68	1.44	2.29	2.10
11	58.5	.40	.32	41.5	2.32	2.02	1.20	1.03	.95	.87
14	68.7	.29	.23	31.3	1.45	1.27	.66	.56	.61	.55
16	72.5	.42	.34	27.5	1.77	1.60	.79	.69	1.02	.90
20	62.9	.42	.32	37.1	2.62	1.40	1.24	.72	1.33	1.21
22	36.7	1.13	1.02	63.3	2.35	2.22	1.90	1.78	1.74	1.57
25	43.3	1.62	1.47	56.7	4.27	3.38	3.13	2.54	2.00	1.86
28	66.3	.32	.27	33.7	2.77	2.48	1.14	1.01	2.00	1.76
AVERAGE	62.0	..75	.65	38.0	2.96	2.41	1.56	1.39	1.57	1.31

LABORATORY AND TEST WORK IN CONNECTION WITH FLOTATION

Each day a grab sample was taken of the flotation feed to determine the water to solid ratio. The ratio usually was around 4.50 to 1. The launder carrying the flotation feed was so constructed that it was possible to completely cut off the stream with a bucket, i.e., to take a sample representing the total feed to the cells. Each morning such a sample was taken, timed with a stop-watch to one-fifth of a second. This sample was dried, weighed and the tonnage to the flotation cells for 24 hours calculated. Grab samples taken with a "cutter", by hand, every hour and representative of the total feed at that time combined into three large samples, each representative of a shift, were taken, dried and assayed. The assays from these samples and a composite made from them to represent the 24 hour run were used as assays of the flotation feed. The tailings were sampled by an automatic sampler, the sample taken filling a twelve quart bucket each shift.

Besides these regular daily samples and tests there were also the dispersion tests previously mentioned as well as screen tests of both feed and tails. Experimental laboratory tests using different kinds and makes of oils, these tests being run on 500 gm. samples of actual flotation plant feed, were constantly being made and recently, as a result of these, Xanthate has been introduced into the plant and had proven highly satisfactory.

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TONNAGE AND COSTS

Taking for example an average month, August,1923, the flotation plant treated 2176 dry tons of ore, shipped 27.51 dry tons of concentrate, containing 116,000 lbs. of copper and 810 ozs. of silver. The cost of production, including royalty, was 4.28¢ per pound of copper produced, on board the car for shipment from Kennecott.

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CONCLUSION

The outstanding features in the flotation process for the recovery of the carbonate copper ore at the Kennecott plant might be summed up as follows:

1. In the strict sense of the term no fine-grinding, although recently some tables in the mill have been discarded and ball mills added.

2. The adding of a sodium sulphide solution as a reagent.

3. The mixing, according to U.S. Agriculture Bulletin #1285, and adding of a sulphur-lime solution.

4. Necessity of constant vigilance in the plant because of the fluctuating proportions of the carbonate ore in the mill feed.

5. The fact that this plant for the flotation of carbonate copper ore has proven a commercial success.

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