THE EFFECTS OF FINE-SIZE PARTICLES
AND pH CONTROL
ON FLUORSPAR FLOTATION

by

Suresh Natverlal Shah

ProQuest LLC.
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 – 1346

A thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science.

Signed: Suresh Natverlal Shah
Suresh Natverlal Shah

Golden, Colorado
Date: Sept. 2, 1954

Approved: A. P. Wichmann
Metallurgy Department

ACKNOWLEDGEMENTS

The author wishes to express his sincere thanks to Professor Arthur P. Wichmann, Head, Department of Metallurgical Engineering, Colorado School of Mines, for cooperation, able guidance, and the keen interest with which he supervised this investigation.

Also thanks are due to Mr. A. L. Pierce, chemist, Experimental Ore Dressing Plant, Colorado School of Mines, who did all the analytical work in connection with this investigation.

CONTENTS

INTRODUCTION

Fluorspar was placed on the list of strategic minerals during World War II. Since then, increasing demands in the metallurgical, ceramic, and chemical industries have necessitated more investigations concerning the concentration of the ore.

Fluorspar is concentrated by gravity-concentration methods like heavy-media separation and jigging. Such methods, however, are limited to ores where the mineral can be separated from the gangue at a relatively coarse size. Intimate association of fluorspar with gangue minerals prevents the use of gravity-concentration methods. In such cases flotation is used as a concentrating method.

In the flotation of fluorspar there is no standard procedure that can be applied to all types of fluorspar ore. Because of variable amounts of different gangue minerals and the properties of fluorite present, each ore has its own characteristics. Consequently the procedure of treatment varies with each ore.

The usual associated minerals in a fluorspar ore are quartz, various silicates (mostly feldspars), calcite, sulphides, iron oxides, barite, and clays.

The reagents generally used in the flotation of fluorspar ore are oleic acid or sodium oleate as a collector for fluorite; quebracho as a depressant for calcite; sodium and soda ash for dispersion and alkalinity regulation; and sodium cyanide for removing the activating effect of iron salts on silica and for depressing pyrite during the flotation of fluorspar.

The following techniques, either singly or in combination, are used commercially for the production of acid-grade fluorspar by flotation.

1. Hot Pulps: This technique involves heating of the pulp to boiling before floating the fluorspar. This method reduces the consumption of reagents and is used where silica is present in large proportions in the ore. Boiling also aids in the emulsification and partial solution of the oleic acid or sodium oleate. According to Cook and Last (1950, p. 6), boiling results in chemical adsorption of the collector on the fluorspar, as opposed to physical adsorption of the collector in a cold circuit.
2. Regrinding of Rougher Concentrates: In this treatment the rougher concentrates of fluorspar are ground to a finer size before recleaning. This grinding is necessary for a better liberation of the fluorspar particles but must not produce too many extremely fine-sized particles.
3. Removal of Fine Particles (Desliming) : The fine-size particles are removed at a predetermined size because the presence of fine particles in flotation tends to increase the losses in tailings or decrease the percentage of recovery,

reduce the selectivity, lower the grade of concentrates, result in excessive consumption of reagents, and in general ruin the effective flotation.

The purpose of this investigation was primarily to determine the effects of fine-size particles on the percentage of recovery, the losses in tailings, and the grade of concentrate. All particles finer than 43 microns are designated as fine-size particles.

The fluorspar used was obtained from Jamestown, Colorado.

The chief mineral constituents of the ore are fluorite, calcite, quartz, iron oxides, pyrite, chalcopyrite, bornite, galena, feldspar, and clays.

The fluorite exists as both a deep violet and a colorless variety. Fluorite grains range in size from 3 to 400 mesh and average about 48 mesh. Most of the sulphide particles average around 150 mesh. However, some intergrown sulphides are finer than 400 mesh.

Grinding of ore is a problem in itself. Various silicates (mostly feldspars and clay-like minerals) are soft and easily ground. Under prolonged grinding these silicates are reduced to fine-size particles. Sulphides and calcite are brittle and are broken down easily. Fluorite and quartz are hard and closely associated. For a good liberation of fluorite the ore needs a slightly prolonged grinding, which in turn produces an excessive amount of fine-size particles.

Fluorite is liberated reasonably well at 100 mesh as indicated by the following results of the microscopic examination:

TABLE I - Microscopic Examination

Mesh Size	Liberation of Fluorite (%)
- 28, + 35	21.6
- 35, + 48	27.1
- 48, + 65	66.7
- 65, +100	82.3
-100, +150	92.0
-150	96.0 or more

The chemical analysis of the ore was as follows:

TABLE 2 - Chemical Analysis

CaF_2	SiO_2	$CaCO_3$	R_2O_3	Insol.	S
59.4%	14.7%	6.34%	8.6%	15.34%	1.65%

SUMMARY

As a result of the test work, the following conclusions were reached:

The pH of the pulp in the flotation of the ore should be maintained at 8.5. Any higher or lower pH has a pronounced effect on the behavior of fine particles to such an extent that the flotation results are impaired.

The use of Emcol X-25 with oleic acid improves the flotation of the ore. Emcol has an emulsifying effect on oleic acid and thus improves the dispersion of the oleic acid.

The fine particles coarser than 10 microns do not produce any deleterious effect on the flotation of the ore. It is the presence of particles finer than 10 microns that ruins the effective flotation of the ore.

EQUIPMENT AND REAGENTS

Equipment

All the test work was done in a 600-gram WEMCO laboratory flotation machine. The impeller speed was 1550 revolutions per minute. The impeller was made of stainless steel and the cell was made of pyrex glass. The chances for contamination, from either the impeller or the cell, when the ore is agitated in an acid circuit, are very remote.

The fine-size separation was made by beaker elutriation. Beakers of 2-liter size were used for this purpose. The pulp in the beaker was stirred by a high-speed stirrer.

Grinding was performed in a 8 x 8-inch cylindrical laboratory ball mill. Both the balls and the liners were made of steel.

Reagents

All the reagents were made up in 10% solutions. The soda ash, sodium silicate, quebracho, sodium cyanide, oleic acid, sodium oleate, z-6 (potassium pentasol amyl xanthate), and the Emcol X-25 were the usual commercially available chemicals.

To prepare the emulsified oleic acid, 9 parts of oleic acid by weight were mixed with 1 part of Emcol X-25 by weight. A 10% solution of this mixture was prepared. Chemically, Emcol X-25 is a sodium salt of a sulpho-acetylated derivative of a mono-glyceride of a fatty acid. It is used as a wetting and emulsifying agent and as a detergent.

DETERMINATION OF OPTIMUM pH

Since the amount of dispersion is a determining factor in the effects of fine-size particles, this series of tests was undertaken to determine the optimum pH of the pulp used in the flotation of the ore.

Experimental Procedure

To obtain comparative results in the tests, all the variables except the pH of the pulp were kept constant. Separate tests were made to determine the amounts of the various reagents best suited to the ore. Optimum skimming time was also determined.

For each test a sample of 600 grams of ore was ground in the laboratory ball mill at a water-to-solids ratio of 3 to 4. Grinding time was 6 min. The ore was ground to about 5% plus 65 mesh.

The pulp was then transferred to the flotation cell and diluted to 20% solids. The pH of the pulps was precisely regulated by sulphuric acid or soda ash. Since the object was to obtain comparative results, the rougher concentrates of fluorspar were not cleaned more than twice. In commercial practice, the rougher concentrates are cleaned five or six times to obtain acid-grade fluorspar concentrate.

All the tests were made in duplicate and since the results of the duplicate tests were very close to those of the original tests, they are not reported. The standard procedure followed for each test was as follows:

Grind - 5% plus 65 mesh

Frother- Pine oil

Reagents Added (lb/ton)	Conditioning Time (min)	Skimming Time (min)
Sulphide Circuit:		
0.20 Z-6	2	
1.00 Na_2SiO_3	2	
0.06 Sulphidizer	2	10
Rougher Circuit:		
0.20 Quebracho	4	
3.00 Na-oleate	4	4
1st Cleaner Circuit:		
1.00 Na-oleate	3	2
2nd Cleaner Circuit:		
None		2

Six sets of tests were made using the above procedure. The results obtained from these tests due to variations in the pH of the pulps are shown under test data.

Test Data

Test 1

pH of pulp - 7.2

	Weight (%)	Assay CaF_2 (%)	Distribution of CaF_2 (%)
Sulphides	4.77	15.1	1.2
Rougher Tails	26.70	25.7	11.5
Cleaner Mids.	17.56	47.1	13.8
Cleaner Conc.	50.97	85.8	73.5
Total	100.00		100.0

Test 2

pH of pulp - 7.6

	Weight (%)	Assay CaF_2 (%)	Distribution of CaF_2 (%)
Sulphides	4.76	15.1	1.2
Rougher Tails	18.54	14.0	4.34
Cleaner Mids.	13.10	26.6	5.82
Cleaner Conc.	63.60	85.0	89.70
Total	100.00		100.00

Test 3

pH of pulp - 8.0

	Weight (%)	Assay CaF_2 (%)	Distribution of CaF_2 (%)
Sulphides	4.08	13.1	0.87
Rougher Tails	21.23	9.8	3.42
Cleaner Mids.	10.79	28.7	5.10
Cleaner Conc.	63.40	86.6	90.61
Total	100.00		100.00

Test 4

pH of pulp - 8.5

	Weight (%)	Assay CaF_2 (%)	Distribution of CaF_2 (%)
Sulphides	3.66	10.9	0.66
Rougher Tails	21.41	9.7	3.48
Cleaner Mids.	11.28	18.5	3.50
Cleaner Conc.	63.65	86.6	92.36
Total	100.00		100.00

Test 5

pH of pulp - 8.75

	Weight (%)	Assay CaF_2 (%)	Distribution of CaF_2 (%)
Sulphides	5.50	22.7	2.10
Rougher Tails	26.00	13.7	6.00
Cleaner Mids.	8.45	31.7	4.50
Cleaner Conc.	60.05	84.4	87.40
Total	100.00		100.00

Test 6

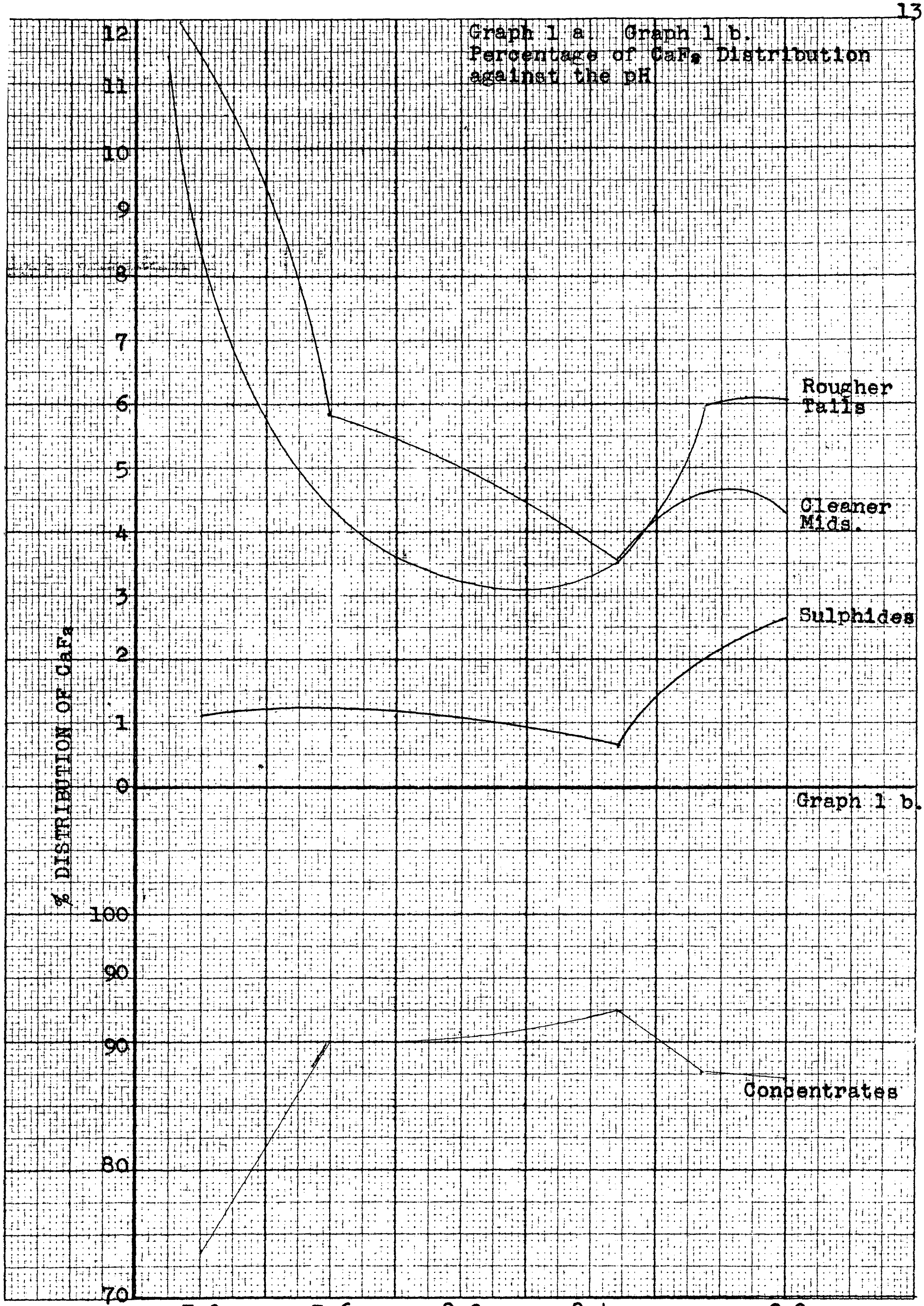
pH of pulp - 9.00

	Weight (%)	Assay CaF_2 (%)	Distribution of CaF_2 (%)
Sulphides	5.66	28.2	2.60
Rougher Tails	25.60	14.5	6.05
Cleaner Mids.	8.39	31.5	4.30
Cleaner Conc.	60.45	88.3	87.15
Total	100.00		100.00

Graph

In Graph 1 (page 13) , the percentages of fluorite distribution in the different products are plotted against the pH values.

At a pH of 8.5, the losses in the sulphides and the tailings are minimum. The percentage of recovery at this pH is maximum. At a pH higher than 8.5, the losses increase again, and the percentage of recovery decreases.


Graph 1 a. Graph 1 b.
Percentage of CaF_2 Distribution against the pH
Rougher Tails
Cleaner Mids.
Sulphides
Graph 1 b.
Concentrates
% DISTRIBUTION OF CaF_2
12
11
10
9
8
7
6
5
4
3
2
1
0
100
90
90
80
70
7.2
7.6
8.0
8.4
9.0
pH

EFFECT OF OLEIC ACID WITH EMCOL X-25

At room temperature oleic acid is not well dispersed when mixed with water alone, as can very readily be seen when oleic acid is mixed with water in a beaker. Because of its lower specific gravity and high surface tension, oleic acid floats on water in the form of tiny globules.

To provide a good dispersion and emulsification of oleic acid, a mixture of oleic acid and Emcol X-25, with the proportions of 9 to 1 by weight, was prepared.

To determine the effect of this emulsified oleic acid, a test was made keeping all the other conditions identical with those of Test 4, which established the optimum pH and where sodium oleate was used as a collector.

Test Data

Test 7

Grind - 5% plus 65 mesh

pH of pulp - 8.5

pH regulated by soda ash

Sulphide Circuit:

Reagents Added (lb/ton)	Conditioning Time (min)	Skimming Time (min)
1.0 Na_2SiO_3	2	
0.20 Z-6	2	
0.06 Sulphidizer	2	10

Rougher Circuit:

Reagents Added (lb/ton)	Conditioning Time (min)	Skimming Time (min)
0.20 Quebracho	4	
2.50 Emulsified Oleic Acid	4	4

1st Cleaner Circuit:

None		2

2nd Cleaner Circuit:

None		2

Results

	Weight (%)	Assay CaF_2 (%)	Distribution of CaF_2 (%)
Sulphides	3.60	10.1	0.60
Rougher Tails	18.50	8.1	2.47
Cleaner Mids.	10.54	12.8	2.23
Cleaner Conc.	67.36	85.3	94.70
Total	100.00		100.00

Comparison

The results of the above tests are compared to those of Test 4 to appraise the effect of emulsified oleic acid to that of sodium oleate.

TABLE 3 - Comparison

	Distribution of CaF_2 in Test 4 (%)	Distribution of CaF_2 in Test 7 (%)
Sulphides	0.66	0.60
Rougher Tails	3.48	2.47
Cleaner Mids.	3.50	2.23
Cleaner Conc.	92.36	94.70
Total	100.00	100.00

It is clearly seen from the comparison that emulsified oleic acid improves the flotation of the ore to some extent. The losses in sulphides and tailings have decreased, and the percentage of recovery has increased.

EFFECTS OF FINE-SIZE PARTICLES

Preparation of Identical Samples of Ore

It was necessary in this series of tests to secure identical conditions for each test as nearly as possible. Ball mill grinding produces slight variations in the amounts of different mesh sizes, even when two samples of ore are ground under exactly the same conditions. To remove these variations arising from ball mill grinding, the following procedure was adopted.

A sample of 6000 grams of the ore was ground in the ball mill. The water-to-solids ratio was 3 to 4, and the grinding time was 6 minutes. The pulp was then screened through 65 mesh. The plus 65- mesh portion was reground under the same conditions. The ground ore was dried and screen analyzed. Thus different portions of different mesh sizes were obtained. Each portion, representing a certain mesh size, was thoroughly mixed and then divided into ten equal parts. This procedure was repeated for each portion. Ten samples, each of 600 grams of ore, were made up, taking one part from each portion. Thus each sample of the ore contained exactly equal amounts of different mesh sizes. The sample thus obtained had the following screen analysis.

TABLE 4 - Screen Analysis

Mesh Size	Weight (%)	Cumulative Weight (%)
+ 65	0.83	.83
- 65, +100	27.95	28.78
-100, +150	21.60	50.38
-150, +200	17.85	68.23
-200, +250	3.21	71.44
-250, +270	4.90	76.34
-270, +325	5.90	82.24
-325 --	17.76	100.00
Total	100.00	

Procedure for Fine-Size Separation

Fine-size particles were separated from the ore by elutriation. The minus 325 mesh portion from each ore was used for this purpose. This portion was put into a 2 liter beaker and 2 liters of water were added to it. For dispersing the fine particles, 0.1 gram of soda ash and 1 milliliter of syrupy sodium silicate were added to the pulp. The pulp was then stirred with a high-speed stirrer for 10 minutes. The fine particles were then allowed to settle for a specific time calculated according to the settling rate of the size of the particles that were to be separated. The settling rate used was based on the settling rate of spherical particles of quartz as reported by Dorr and Bosqui (1950, p. 23). The supernatant liquid, which contained in suspension the fine particles that were to be separated, was poured off.

The settled particles in the beaker were cleaned twice more in the same manner as above. All the supernatant liquid was filtered, and the fine-size fraction was dried. These fractions are reported in the results of each test as "Fine Size." The sizes in which the particles were separated for different tests were minus 43, minus 20, minus 10, and minus 5 microns.

Experimental Procedure

After making the fine-size separation, each sample of ore was floated in the laboratory flotation machine. The procedure was established by separate tests. The pH of the pulp was maintained at 8.5. The amount of emulsified oleic acid added was increased to provide sufficient amount of collector for the fine particles. Sodium cyanide was used in this series of tests since it was found to have depressing effect on silica. Pine oil was used as a frother. Each test was made in duplicate. The results of these duplicate tests , being very close are not reported. The following procedure was used for each test:

Sulphide Circuit:

Reagents Added (lb/ton)	Conditioning Time (min)	Skimming Time (min)
2.0 Soda Ash	3	
0.4 Z-6	2	
0.15 Sulphidizer	2	15

Rougher Circuit:

Reagents Added (lb/ton)		Conditioning Time (min)	Skimming Time (min)
1.5	Na_2SiO_3	3	
0.3	NaCN	2	
0.5	Quebracho	4	
4.0	Emulsified Oleic Acid	4	
2.0	Na_2CO_3	3	4
1st Cleaner Circuit:			
0.5	Quebracho	3	2
2nd Cleaner Circuit:			
0.5	Na_2CO_3	3	2
3rd Cleaner Circuit:			
None			2

Test Data

Test 8

Fine-size separated -- minus 43 microns (-325 mesh)

	Weight (%)	Assay CaF_2 (%)	Distribution of CaF_2 (%)
Sulphides	3.46	10.00	0.57
Rougher Tails	23.92	16.80	6.72
Cleaner Mids.	9.42	44.00	6.94
Cleaner Conc.	45.20	90.60	68.50
Fine-Size	18.00	57.40	17.27
Total	100.00		100.00

Test 9

Fine-size separated --minus 20 microns

	Weight (%)	Assay CaF_2 (%)	Distribution of CaF_2 (%)
Sulphides	3.86	11.7	0.76
Rougher Tails	28.80	16.00	7.74
Cleaner Mids.	12.00	53.25	10.76
Cleaner Conc.	46.91	91.40	73.52
Fine-Size	8.43	50.10	7.22
Total	100.00		100.00

Test 10

Fine-size separated --minus 10 microns

	Weight (%)	Assay CaF_2 (%)	Distribution of CaF_2 (%)
Sulphides	4.01	13.1	0.88
Rougher Tails	29.50	16.5	8.14
Cleaner Mids.	14.20	53.0	12.58
Cleaner Conc.	50.25	91.5	77.00
Fine-Size	2.04	42.0	1.40
Total	100.00		100.00

Test 11

Fine-size separated --minus 5 microns

	Weight (%)	Assay CaF_2 (%)	Distribution of CaF_2 (%)
Sulphides	3.61	13.1	0.78
Rougher Tails	35.00	22.6	13.20
Cleaner Mids.	14.58	63.1	15.30
Cleaner Conc.	45.63	91.9	70.00
Fine-Size	1.18	38.2	0.72
Total	100.00		100.00

Test 12

Fine-size not separated (entire sample)

	Weight (%)	Assay CaF_2 (%)	Distribution of CaF_2 (%)
Sulphides	3.90	16.20	1.05
Rougher Tails	32.50	23.00	12.90
Cleaner Mids.	16.81	52.00	14.70
Cleaner Conc.	46.79	90.70	71.35
Total	100.00		100.00

To present the effects of fine-size particles more clearly, the following table is prepared. The CaF_2 content of the products in Test 8 is taken as the basis, since in Test 8 all the fine particles (minus 43 microns) were separated. Increase in CaF_2 content of every product as related to the same product in Test 8 is indicated.

TABLE 5 - Increase in CaF_2-content in the products (on the basis of same products in Test 8) of tests, where the fine-size was separated at microns

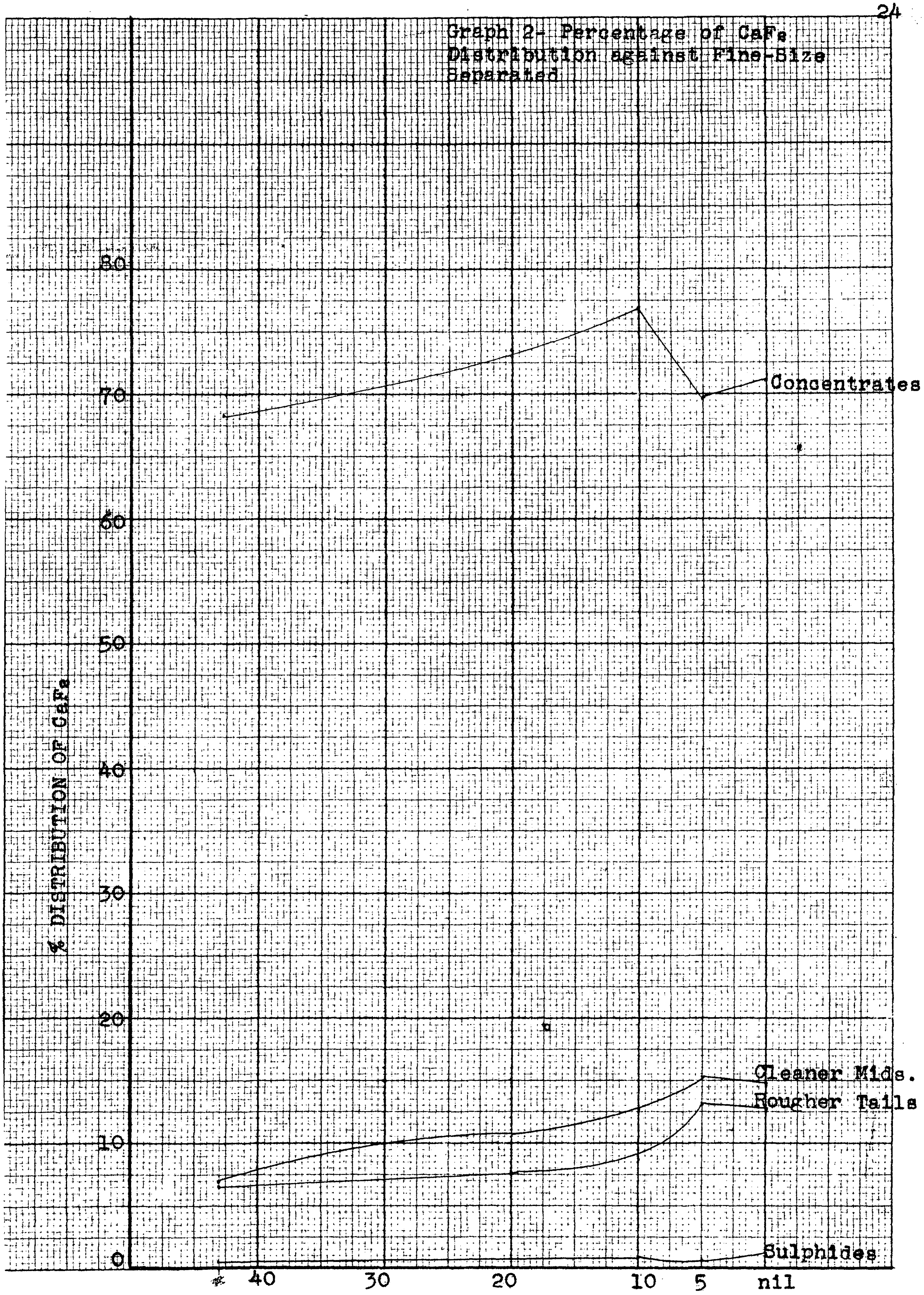
	-20 (%)	-10 (%)	-5 (%)	Nil (%)
Sulphides	0.19	0.31	0.21	0.48
Rougher Tails	1.02	1.42	6.48	6.18
Cleaner Mids.	3.82	5.64	8.36	7.76
Cleaner Conc.	5.02	8.50	1.50	3.05

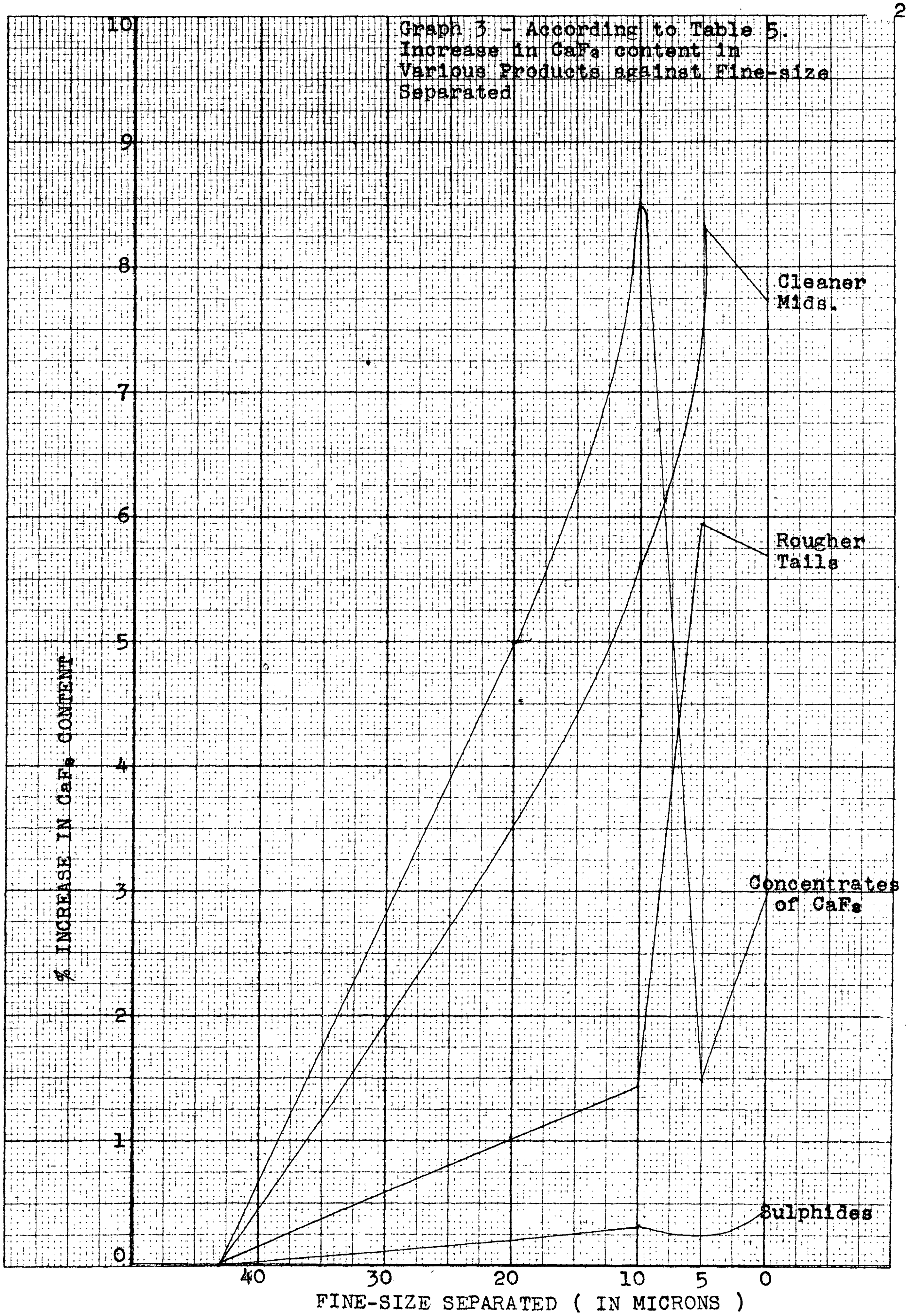
Graphs

In Graph 2 (page 24) the CaF_2 content of the products is plotted against the separated fine-sizes. The graph shows steady increase in the CaF_2 content of various products of tests, where the finest size present is 20 microns. However, when particles finer than 20 microns are present, the losses increase sharply and the percentage of recovery decreases.

Graph 3 (page 25) essentially shows the same features as Graph 2 but in a magnified form. This graph is plotted according to Table 5 (page 23).

Graph 2- Percentage of CaF_2 Distribution against Fine-Size Separated





Graph 3 - According to Table 5. Increase in CaF_2 content in Various Products against Fine-size Separated

THEORETICAL ANALYSIS OF THE RESULTS

Determination of the optimum pH

Graph 1 (page 13) shows that the optimum results in the flotation of the ore are obtained at a pH of 8.5. At this pH, the percentage of recovery is maximum and the losses in the sulphides and the tailings are at a minimum.

At a pH lower than 8.5, the pulp is not well dispersed. The results show that the dispersion in the pulp is an important factor in the flotation of the ore. Dispersion gives a better opportunity to the collector to coat the particles selectively so that they are easily attached to the bubbles and floated. Moreover, the fine particles have a tendency to form floccules, which resist the formation of collector coating. Eventually these floccules are lost in the tailings. Under these circumstances, dispersion is the only way by which the fine particles can be reached by the collector.

At a pH higher than 8.5, the zeta potential decreases and the fine particles tend to form floccules, which impair the results of flotation.

According to Gaudin (1939, p. 388), the control of the pH is important in two ways. First, the concentration of soluble salts can be reduced to the point where the tendency for the surfaces to become alike is kept within bounds. Second, a soluble salt that consumes the collector may be "locked up" as a precipitate, in which form it consumes less collector.

Use of Oleic Acid with Emcol X-25

The use of emulsified oleic acid as a collector, as compared to sodium oleate, definitely improves the results of the flotation as shown in Table 3 (page 16).

Oleic acid when emulsified with Emcol X-25 is well dispersed. Then it has a better opportunity to coat the particles of the valuable mineral selectively.

Effects of Fine-Size

Graph 2 (page 24) shows the effect of different sizes of fine particles on the flotation of the ore.

As mentioned before, generally the presence of fine-size particles increases the losses in tailings, decreases the percentage of recovery, and lowers the grade of concentrates.

In the flotation of this ore, however, the effects of fine particles are somewhat peculiar. The losses in sulphides and tailings do increase with the increase in different sizes of fine particles. The grade of concentrates, however, increases. The percentage of recovery also increases, except where the fine particles of only minus 5-micron-size are separated. To understand this behavior it is necessary to analyze the results carefully.

Graph 3 (page 25) shows that the sulphides, tailings, and concentrates are steadily increasing in their CaF_2 content as long as the minus 10-micron-size fraction is out of the sample of ore. But when only the minus 5-micron-size fraction is separated, leaving plus 5-micron-size fraction in the ore, the tailings increase sharply in their CaF_2 content, and the concentrates decrease sharply in their CaF_2 content. When all the fine-size particles are present in the ore, the losses in tailings do not increase any more, nor does the percentage of recovery decrease, but the grade of concentrate decreases.

Therefore, it can be inferred that the particles finer than 10 microns produce very harmful effects.

As long as the particles finer than 10-micron size are removed from the sample of the ore, the CaF_2 content increases steadily in all the products. This shows that the fine particles coarser than 10-micron size do not produce any deleterious effects by the nature of their surfaces or for any other reason. If this were not the case, all the products would not have increased in their CaF_2 content simultaneously.

The exact nature of behavior, or the process by which the particles finer than 10 microns produce harmful effects, is difficult to state. There have been many assumptions and hypotheses, of which any one or more of the following might be true.

1. Flocculation: Gaudin (1932, p. 48) has shown that flocculation begins when the particles are finer than 8 microns. Flocculation prevents the coating by the collector and so the floccules are not attached to the bubbles.

2. Mutual Precipitation of Colloids: As indicated by Ince (1930, p. 261), certain minerals, in similar aqueous solutions, are positively charged, whereas others are negatively charged. These charged minerals discharge each other forming flocs, which are very harmful in the flotation.
3. Surface changes and Surface Films: Gaudin (1943, p. 473) and his co-workers have indicated that the finer the particles, the more advanced are the surface reactions that might form films on the surface of the particles, which are then not easily coated by the collector.
4. Cementing Hypothesis: Del Giudice (1934, p. 398) has shown that some minerals, by ionic exchange in the solutions in the pulp, form substances at the surface that act as a binding cement between the valuable and the gangue mineral particles.
5. Ionic Hypothesis: Sun (1943, p. 479), on the basis of ionic zeta potentials, theorizes that the magnitude and sign of the ionic charges on the coarse and fine particles control the fine-particle coating.

CONCLUSIONS

The following conclusions were reached as a result of the test work:

In the flotation of this ore the optimum pH is 8.5 Any higher or lower pH tends to impair the results of the flotation. This is so because at lower pH, the dispersion is not sufficient to allow the collector to coat the maximum number of particles of the valuable mineral. At a higher pH, on the other hand, the decrease in zeta potential starts the flocculation of fine particles. This flocculation impairs the results of flotation.

The use of Emcol X-25 definitely improves the results of the flotation. This is because Emcol X-25 emulsifies and disperses oleic acid well.

The particles coarser than 10 microns do not produce any deleterious effects in the flotation of the ore. Particles finer than 10 microns are very harmful in the flotation of the ore. These particles by their changed surface conditions increase the losses in tails as well as decrease the percentage of recovery. Moreover, these particles approach the size of true colloids. The surface energy becomes relatively the most important property, which governs their behavior during flotation, regardless of mineral species.

BIBLIOGRAPHY

1. Cook, M. A., and Last, A. W., Theory of oleic acid collector action: University of Utah, Bull. no. 47, vol. 40, no. 14, 1950.

2. Gaudin, A. M., Flotation: New York, McGraw-Hill Book Company, Inc., 1932.

3. Gaudin, A. M., Groh, J. O., and Henderson, H. B., Effect of particle size on flotation: Am. Inst. Min. Met. Eng., Tech. Pub., 414, 1931.

4. Gaudin, A. M., Principles of mineral dressing: New York, McGraw-Hill Book Company, Inc., 1939.

5. Gaudin, A. M., and Mulozemoff, P., Hypothesis for the non-flotation of sulphide minerals of near colloidal size: Am. Inst. Min. Met. Eng., Trans., vol. 153, 1943.

6. del Giudice, G. R. M., A study of slime-coating in flotation: Am. Inst. Min. Met. Eng., Trans., vol. 112, 1934.

7. Sun, S. C., The mechanism of slime-coating: Am. Inst. Min. Met. Eng., Trans., vol. 153, 1943.

8. Ince, C. R., Am. Inst. Min. Met. Eng., Trans., vol. 87, 1930.

9. Taggart, A. F., Elements of ore dressing: New York, John Wiley and Sons, Inc., 1952.

10. Wark, I. W., Principles of flotation: Melbourne, Australasian Inst. of Min. and Metallurgy, 1938.