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EFFECT OF GANGUE PARTICLE SIZE ON FLOTATION

By

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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 with a major in Metallurgical Engineering.

Signed

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Golden, Colorado

Date January 18, 1952

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INTRODUCTION

To date there has been no agreement as to the definition of the term slime, though slime creates an important problem in the field of flotation. Some writers^{1,2/} have designated slime as crushed rock in water when the rock is of such fineness that it will pass a 150- or 200-mesh screen. In 1945 Taggart^{3/} defined slime as materials fine enough to remain suspended more or less indefinitely in a suitable pulp solution. Such material is frequently characterized as colloidal slime. However, E. K. Fisher^{4/} writes that colloidal particles vary from approximately 1 micron size found in suspension to 1 millimicron size found in solution. In an effort to avoid vagueness, "slimes" are designated by the term particle size in this thesis.

It is evident that increased information about the varied behaviors of different particle sizes in flotation would be of practical as well as of theoretical interest. The object of this study has been to determine the effect of gangue particles finer than 200 mesh on the flotability of a mixture of pure-sized minerals.

In 1931, Gaudin, Groh, and Henderson^{5/} considered the method of mixing pure-sized minerals impractical because of tediousness involved by the large amount of elutriation required preparatory to flotation. The introduction of the Haultain Infrasizer in recent years has been a great aid in sizing particles smaller than 200 mesh.

A large number of minerals in various concentrates are concentrated by the froth flotation process. The extremely small particles, or "slimes," of most minerals cause difficulty and decrease the efficiency of the concentration process.

In order to confine the scope of the problem of small particle size within reasonable limits, as a beginning, the author has limited the experiments described herein to measured additions of increasing weights of gangue particles in various fine-size ranges, to a synthetic ore consisting of one gangue mineral and one valuable mineral.

By holding all other flotation variables constant, it is hoped to shed some light on the effect of increasing weights of "slimes," or small-size-range gangue particles, on the grade of concentrate and recovery in the process.

THEORIES

Effect of Particle Size on Flotation

The presence of fine particles, or "slimes," in a flotation pulp causes a series of physical and physical-chemical phenomena that adversely affect the consumption of reagents and cause overfrothing, contamination of concentrate, and reduction in recovery.

Effect on consumption of reagents by fine particles, or "slimes," is not serious in sulphide flotation, although a few investigators report the necessity for the use of more frother or collector or both when colloidal "slimes" are present. But in non-sulphide flotation, colloidal "slimes" usually consume excessive quantities of fatty acid soaps or cationic collectors. Consumption of the reactive collector is believed to be caused by both chemical reaction and collector coating. These cause excessive consumption of reagents, often in amounts ten or more times those ordinarily required. As a result, the interface of the air bubble and the liquid is coated with small-size gangue particles, or "slimes," and presents a gangue surface to the valuable mineral particle when contact of bubble and mineral particle takes place, thus preventing attachment of the mineral particle to the bubble. The action with the frothers is coating of the droplets, which are thus stably insulated and armored, not only against coalescence with each other, but against their proper functions of attaching themselves to the granular mineral to be floated.

Overfrothing applies to any condition of a froth involving an uncontrollable amount of froth. Overfrothing is usually marked by a fluffy, large-bubble froth of large volume, carrying little or no ore solids, or carrying all minerals without apparent selectivity. With sulphide ores the solids carried are frequently predominantly gangue. Overfrothing of a mineral pulp is usually due to the formation of a skin of solid or semisolid character around the bubbles, ordinarily formed of colloidal materials present in the pulp. The undesirable effect increases with increase in surface activity of the colloid. The film apparently excludes granular material mechanically from the interfaces occupied by the "slimes," or fine ore particles.

Contamination of concentrate by gangue "slimes" occurs primarily in nonsulphide flotation when the gangue "slimes" are flocculated and more or less collector-coated, and are floated. There is minor contamination, both in sulphide and nonsulphide flotation, by dispersed "slimes" carried in suspension in the water, and by reason of "slime" coating of granular material that is floated.

Reduction in recovery occurs when "slime" coating of granular material otherwise floatable may occur to such an extent as to prevent bubble attachment. As a rule, "slimes" of all minerals are very slow in floating.

Hypotheses of Slime-Coating Mechanism

Slime coating is caused, on the basis of the available evidence, by the following four mechanisms.

An old hypothesis of gangue slime coating of valuable minerals was proposed by C. R. Ince^{6/}. Ince states that this is due to the attraction between electrostatic charges of opposite sign on the sulphide and on the gangue slime particles.

The ionic theory was further revised by S. C. Sun^{7/}. Sun concludes that slime coating is heavy when the potentials of granular particle and slime are high and of opposite sign, and/or when the potential of the slime is low; that the coating is light when the potential of the slime is high and that of the particle low, or when both potentials are high but alike in sign.

Del Giudice in a cementing hypothesis^{8/} postulated in 1934 showed that certain cases of coating--e.g., calcite on galena--were accompanied by an exchange of ions in solution in the pulp, carbonate ion leaving and sulfate ion appearing. This indicates reaction at the galena surface resulting in the formation of lead carbonate, which del Giudice postulated to act as a binding cement between the calcite particles and the galena mass.

A flocculation hypothesis by S. G. Bankoff^{9/} states that when conditions in a pulp favor complete flocculation, the granular particles become slime-coated. It had already been shown by Taggart, Taylor, and Knoll^{10/} that when pulp solids are dispersed they are in Brownian movement and that the conditions in the pulp are such as to produce at the particle surface a compound having a bulk solubility of 0.5 to 15 or 20 milligrams per liter. The condition for dispersion is the

combination of anchored and free-swimming ions. Surface compounds too soluble to permit anchorage produce flocculation, as do also coatings too slightly soluble to permit a suitable atmosphere of surrounding free-swimming ions. Observation of slime pulps under a microscope shows that the particles in a thoroughly dispersed pulp never made contact with each other, despite their continuous darting movements, but that when Brownian movement is stopped, either by over-solubilizing or closing the particle surfaces, the particles, moving along in liquid currents, contact and adhere--i.e., flocculate. Slime coating corresponds to failure of Brownian movement which occurs in pulp atmospheres that produce relatively soluble or highly insoluble particle surfaces.

EXPERIMENTS

Procedure

Five-hundred gram samples of a synthetic ore, composed of 475 grams of minus 65 plus 100 mesh quartz and 25 grams of minus 65 plus 100 mesh galena, were floated in a 600-gram WEMCO laboratory flotation machine in 2,000-2,200 cubic centimeters of Golden tap water. Amounts varying from 5 to 100 grams at 5-gram intervals, and sizes from minus 200 mesh down to a fraction of a micron of fine quartz particles in short size ranges were added. Two minutes were allowed for mixing. Then 5 cubic centimeters of 1-percent (Z-5) amyl xanthate collector equivalent to 0.2 pound reagent per ton of ore was added, and conditioned for 3 minutes. This was followed by the addition of 4 drops of pine oil, equivalent to approximately 0.1 pound per ton, and again conditioning for 1 minute. Air was turned on. As much galena as possible was skimmed. One additional drop of pine oil was added, and the froth was skimmed again. The concentrate was filtered, washed, dried, weighed, and sent to the chemist for analysis of lead.

The following items were kept constant throughout the experiments:

1. Six-hundred-gram Fagergren Laboratory Flotation Machine.
2. From 2,000 to 2,200 cubic centimeters of Golden tap water.
3. The pH was the natural pH, around 7.2.

4. No flocculators or deflocculators were added.
5. Five cubic centimeters of 1-percent Z-5 (amyl xanthate, Dow Chemical Company), freshly prepared.
6. Four drops pine oil in first addition, and 1 drop in later addition.
7. Quartz, secured from Bergen Park, 15 miles from Golden, Colorado, relatively pure white quartz.
8. All the quartz and galena of minus 65 plus 100 mesh fraction being wet screened, dried, and screened again.
9. Amount of synthetic ore, 500 grams.
10. Grade of the synthetic ore, 5% PbS and 95% SiO₂, i.e., 25 grams PbS and 475 grams SiO₂.
11. Mixing time, about 2 minutes.
12. Conditioning time for collector, 3 minutes.
13. Skimming time, as long as the galena particles appeared in froth as a dark color.
14. The minus 200 plus 270 mesh size fraction, and the minus 270 plus 325 mesh size fraction were prepared by screening on Rotap.
15. The particles from minus 325 mesh down to infinitesimal size were separated by the Haultain Infrasizer. (Please refer to the Infrasizer Separation.)
16. Blank tests, e.g., without fine particle addition, were run several times to establish a standard skimming procedure. This resulted in an average concentrate grade of 90% PbS, and 24 grams out of 25 grams of PbS recovery.

Infrasizer Separation

Three 100-gram samples of minus 325-mesh quartz were placed into the sixth cone of the Infrasizer successively. The first 100-gram sample was processed for 15 minutes; the second, 15 minutes; and the last, 30 minutes. All the quartz in the sixth cone was then emptied and placed back into the first cone of the Infrasizer, and processed for 3 hours. The first two cones were practically empty. Six batches of 300 grams each were examined microscopically for their particle sizes.

The diameters of quartz particles recovered from the cones of the Haultain Infrasizer were found to be as follows:

Cone 3	Between 58 microns and 42 microns.
Cone 4	Between 42 microns and 33 microns.
Cone 5	Between 33 microns and 22 microns.
Cone 6	Between 22 microns and 14 microns.
Cone 7	Minus 14 microns.

Tabulation of ResultsTable I - Effect of -200 +270 Mesh Size Particles

Exp. No.	Wt. of Fines Added (grams)	CONCENTRATES			Pbs RECOVERED	
		Wt. (grams)	Pb (%)	PbS (%)	Grams	%
1	5	26.9	76.0	87.8	23.6	94.4
2	10	27.6	75.8	87.6	24.2	96.8
3	15	26.4	77.5	89.5	23.6	94.4
4	20	26.1	78.2	90.3	23.6	94.4
5	25	26.4	77.6	89.6	23.6	94.4
6	30	26.5	77.4	89.4	23.6	94.4
7	35	26.0	80.9	93.4	24.2	96.8
8	40	26.1	78.4	90.5	23.6	94.4
9	45	26.2	80.2	92.6	24.2	96.8
10	50	27.1	77.0	88.9	24.1	96.4
11	55	27.6	75.4	87.1	24.0	96.0
12	60	26.5	78.4	90.5	24.0	96.0
13	65	27.9	74.4	85.9	24.0	96.0
14	70	27.3	76.0	87.8	24.0	96.0
15	75	27.6	76.8	88.7	24.4	97.6
16	80	26.9	77.0	88.9	23.9	95.6
17	85	26.8	78.6	90.8	24.2	96.8
18	90	26.2	79.6	91.9	24.0	96.0
19	95	27.4	75.2	86.8	23.8	95.2
20	100	27.3	75.6	87.3	23.8	95.2

Table II - Effect of -270 +325 Mesh Size Particles

Exp. No.	Wt. of Fines Added (grams)	CONCENTRATES			PbS RECOVERED	
		Wt. (grams)	Pb (%)	PbS (%)	Grams	%
21	5	24.8	81.2	93.8	23.3	93.2
22	10	25.3	80.4	92.9	23.4	93.6
23	15	25.7	80.4	92.9	23.8	95.2
24	20	25.2	81.3	93.9	23.7	94.8
25	25	25.1	82.9	95.7	24.0	96.0
26	30	25.2	81.7	94.4	23.8	95.2
27	35	25.9	79.8	92.2	23.9	95.6
28	40	26.4	79.0	91.3	24.0	96.0
29	45	26.9	78.0	90.1	24.2	96.8
30	50	26.3	79.6	91.9	24.1	96.4
31	55	26.6	77.8	89.9	23.9	95.6
32	60	26.5	78.2	90.3	23.9	95.6
33	65	26.9	76.2	88.0	23.8	95.2
34	70	26.3	77.4	89.4	23.5	94.0
35	75	26.2	78.0	90.1	23.6	94.4
36	80	27.8	74.7	86.3	23.9	95.6
37	85	27.2	75.8	87.5	23.8	95.2
38	90	28.1	74.1	85.6	24.0	96.0
39	95	28.3	73.7	85.1	24.0	96.0
40	100	29.2	70.4	81.3	23.7	94.8

Table III - Effect of 58 - 42 Micron Size Particles

Exp. No.	Wt. of Fines Added (grams)	CONCENTRATES			PbS RECOVERED	
		Wt. (grams)	Pb (%)	PbS (%)	Grams	%
41	5	27.3	77.4	89.4	24.4	97.6
42	10	30.6	68.4	79.0	24.2	96.8
43	15	30.6	65.5	75.7	23.2	92.8
44	20	31.8	65.5	75.7	24.0	96.0
45	25	30.4	66.8	77.1	23.4	93.6
46	30	30.6	66.1	76.3	23.3	93.2
47	35	30.6	67.2	77.7	23.8	95.2
48	40	29.8	69.2	79.9	23.8	95.2
49	45	36.1	59.2	68.4	24.7	98.8
50	50	32.7	64.0	73.9	24.1	96.4
51	55	33.9	62.1	71.9	24.3	97.2
52	60	33.8	60.5	70.1	23.6	94.4
53	65	34.8	60.0	69.3	24.1	96.4
54	70	34.8	60.3	69.6	24.2	96.8
55	75	31.8	66.3	76.5	24.3	97.2
56	80	38.0	53.0	61.3	23.3	93.2
57	85	42.9	48.0	55.5	23.8	95.2
58	90	41.2	49.1	56.8	23.4	93.6
59	95	33.8	57.6	66.5	22.5	90.0
60	100	81.5	23.6	27.3	22.2	88.8

Table IV - Effect of 42 - 33 Micron Size Particles

Exp. No.	Wt. of Fines Added (grams)	CONCENTRATES			Pbs RECOVERED	
		Wt. (grams)	Pb (%)	PbS (%)	Grams	%
61	5	28.5	73.1	84.4	24.1	96.1
62	10	30.9	66.6	77.0	23.8	95.2
63	15	27.9	73.3	84.6	23.6	94.4
64	20	29.0	70.1	81.0	23.5	94.0
65	25	28.0	73.2	84.5	23.6	94.4
66	30	30.8	67.2	77.6	23.8	95.2
67	35	29.9	73.6	85.0	25.4	--
68	40	29.1	65.4	75.5	22.0	88.0
69	45	38.7	54.2	62.6	24.2	96.8
70	50	58.2	36.6	42.3	23.6	98.4
71	55	29.8	70.8	81.6	24.3	97.2
72	60	31.4	66.6	76.9	24.1	96.4
73	65	31.5	66.7	77.0	24.2	96.8
74	70	30.4	69.3	80.0	24.3	97.2
75	75	31.2	68.3	78.9	24.5	98.0
76	80	35.0	60.0	69.3	24.2	96.8
77	85	50.2	41.6	48.0	24.1	96.4
78	90	37.4	57.4	66.2	24.8	99.2
79	95	58.8	34.4	39.7	23.3	92.2
80	100	55.9	36.0	41.6	23.3	93.2

Table V - Effect of 33 - 22 Micron Size Particles

Exp. No.	Wt. of Fines Added (grams)	CONCENTRATES			PbS RECOVERED	
		Wt. (grams)	Pb (%)	PbS (%)	Grams	%
81	5	27.5	76.8	88.7	24.4	97.6
82	10	30.7	68.2	78.8	24.2	96.8
83	15	28.9	69.2	80.0	23.1	92.4
84	20	28.9	70.6	81.5	23.5	94.0
85	25	32.8	53.2	61.4	20.1	80.4
86	30	27.8	68.6	79.2	22.0	88.0
87	35	27.9	75.0	86.6	24.1	96.4
88	40	27.9	74.4	85.9	23.9	95.6
89	45	32.4	65.2	75.3	24.4	97.6
90	50	31.5	65.3	75.4	23.7	94.8
91	55	30.5	67.6	78.0	23.8	95.2
92	60	32.5	65.0	75.0	24.3	97.2
93	65	38.8	54.7	63.1	25.3	--
94	70	40.3	51.2	59.1	23.8	95.2
95	75	45.7	46.0	53.1	24.3	97.2
96	80	41.6	48.8	56.5	24.5	98.0
97	85	49.7	38.1	44.1	21.9	87.6
98	90	47.2	45.2	55.2	26.0	--
99	95	68.0	25.0	28.8	19.6	78.4
100	100	81.5	23.8	27.4	22.2	88.8

Table VI - Effect of 22 - 14 Micron Size Particles

Exp. No.	Wt. of Fines Added (grams)	CONCENTRATES			PbS RECOVERED	
		Wt. (grams)	Pb (%)	PbS (%)	Grams	%
101	5	32.1	67.4	77.8	24.9	99.6
102	10	36.2	57.8	66.8	24.2	96.8
103	15	31.0	65.1	75.2	23.4	93.6
104	20	31.0	67.1	77.5	24.0	96.0
105	25	28.1	73.8	85.1	23.9	98.6
106	30	29.0	72.2	83.4	24.2	96.8
107	35	30.6	68.4	79.0	24.0	96.0
108	40	30.3	67.0	77.4	23.5	94.0
109	45	32.9	63.0	72.8	23.9	95.6
110	50	35.0	60.7	70.1	24.5	98.0
111	55	38.4	54.0	62.4	23.9	95.6
112	60	34.7	57.4	66.3	23.0	92.0
113	65	37.7	54.0	62.4	23.5	94.0
114	70	36.2	47.0	54.3	19.7	78.8
115	80	64.8	25.6	39.6	25.5	--
116	90	66.0	32.4	37.4	21.4	85.6
117	100	68.1	29.6	34.2	23.3	93.2

Table VII - Effect of 14 - Fractional Micron Size Particles

Exp. No.	Wt. of Fines Added (grams)	CONCENTRATES			PbS RECOVERED	
		Wt. (grams)	Pb (%)	PbS (%)	Grams	%
118	5	27.6	74.9	86.5	23.9	95.6
119	10	42.7	48.8	56.4	24.1	96.4
120	15	27.5	73.9	85.3	23.4	93.6
121	20	31.1	66.8	77.1	24.0	96.0
122	25	26.9	77.2	89.0	23.9	95.6
123	30	30.2	69.0	79.7	24.1	96.4
124	35	32.4	64.6	74.6	24.1	96.4
125	40	27.9	73.0	84.3	23.5	94.0
126	45	29.2	71.4	82.4	24.1	96.4
127	50	32.1	66.0	76.3	24.4	97.6
128	55	34.2	60.7	70.1	24.0	96.0
129	60	25.3	79.0	91.2	23.1	92.4
130	65	34.8	58.8	67.9	23.6	94.4
131	70	45.6	47.0	54.3	24.7	98.8
132	75	39.6	41.4	47.8	18.9	75.6
133	80	42.7	47.4	54.7	23.4	93.6
134	85	39.0	52.5	60.6	23.7	94.8
135	90	34.9	3.0	3.5	1.2	--
136	95	58.1	35.4	40.8	23.7	94.8
137	100	58.5	34.2	39.5	23.1	92.4

Fig. 1.
Effect of -200 +270 Mesh Size Particles

Grade of Concentrate
(% PbS)

100

90

80

70

60

50

40

30

20

10

0

Recovery
(Gm PbS) (% PbS)
25 100

23 92

21

10 20 30 40 50 60 70 80 90 100

Gram of -200 +270 Mesh Size Quartz Added

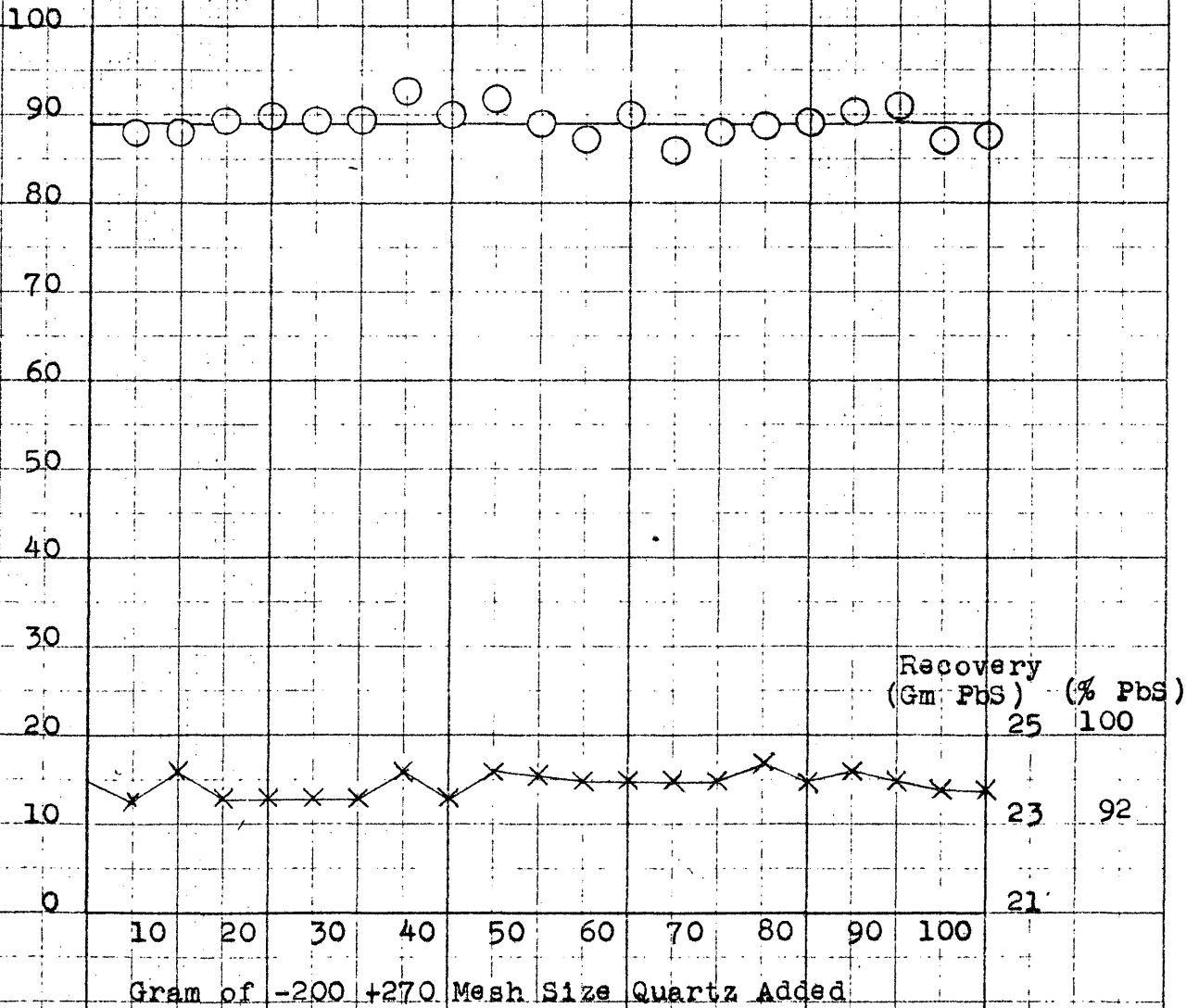


Fig. 2.

Effect of -270 +325 Mesh Size Particles

Grade of Concentrate
(% PbS)

100

90

80

70

60

50

40

30

20

10

0

Recovery
(Gm PbS) (% PbS)
25 100

23 92

21

10 20 30 40 50 60 70 80 90 100

Gram of -270 +325 Mesh Size Quartz Added

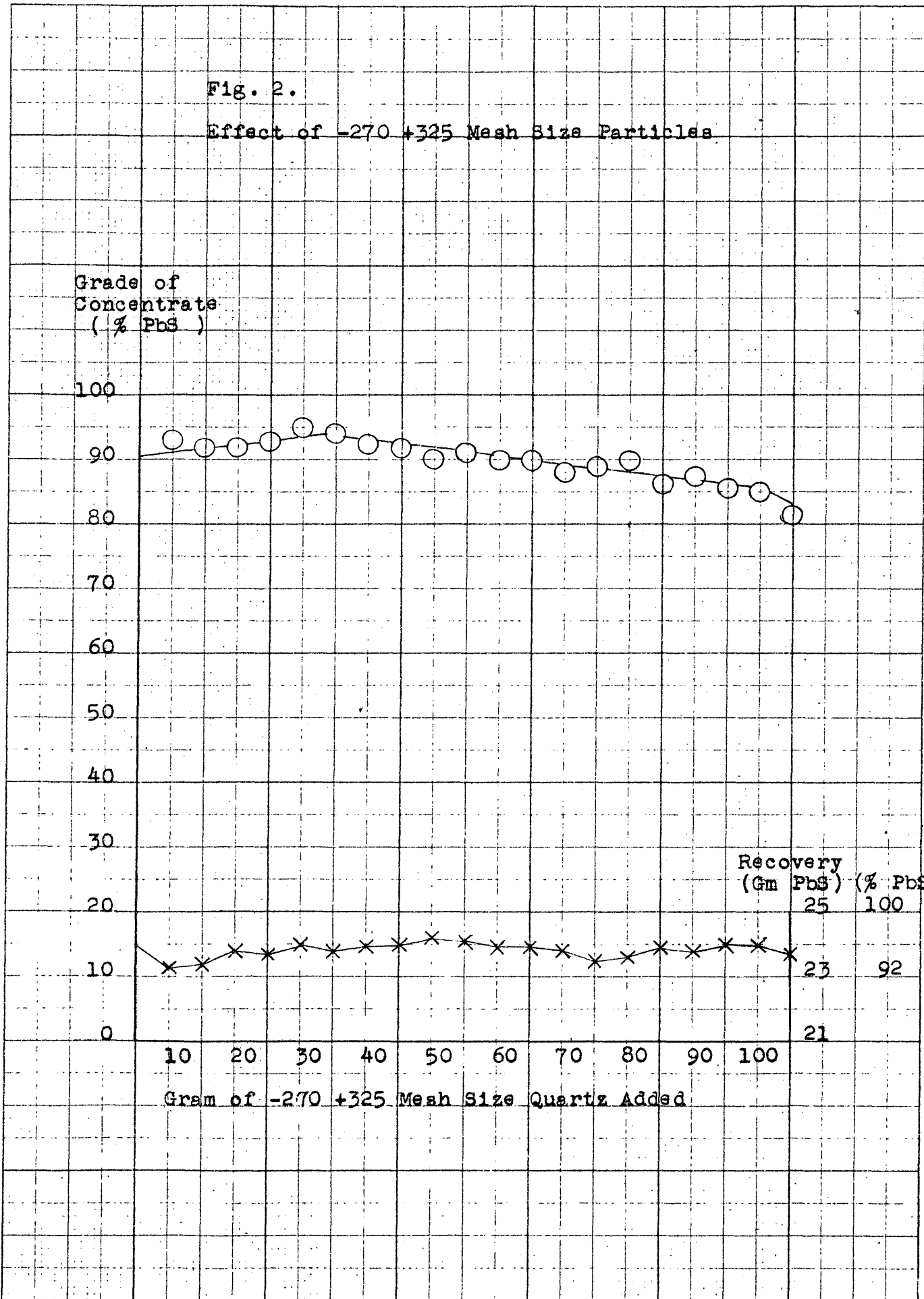


Fig. 3.

Effect of 58 - 42 Micron Size Particles

Grade of Concentrate
(% Pbs)

100

90

80

70

60

50

40

30

20

10

0

Recovery
(Gm Pbs) (% Pbs)

25

100

23

92

21

Gram of 58 - 42 Micron Size Quartz Added

10

20

30

40

50

60

70

80

90

100

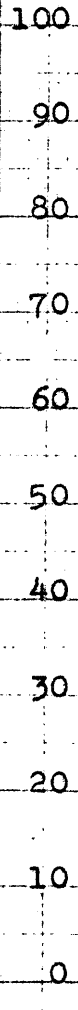


Fig. 4.

Effect of 42 - 33 Micron Size Particles

Grade of Concentrate
(% PbS)

100

90

80

70

60

50

40

30

20

10

0

Recovery
(Gm PbS) (% PbS)

25

100

23

92

21

Gram of 42 - 33 Micron Size Quartz Added

10

20

30

40

50

60

70

80

90

100

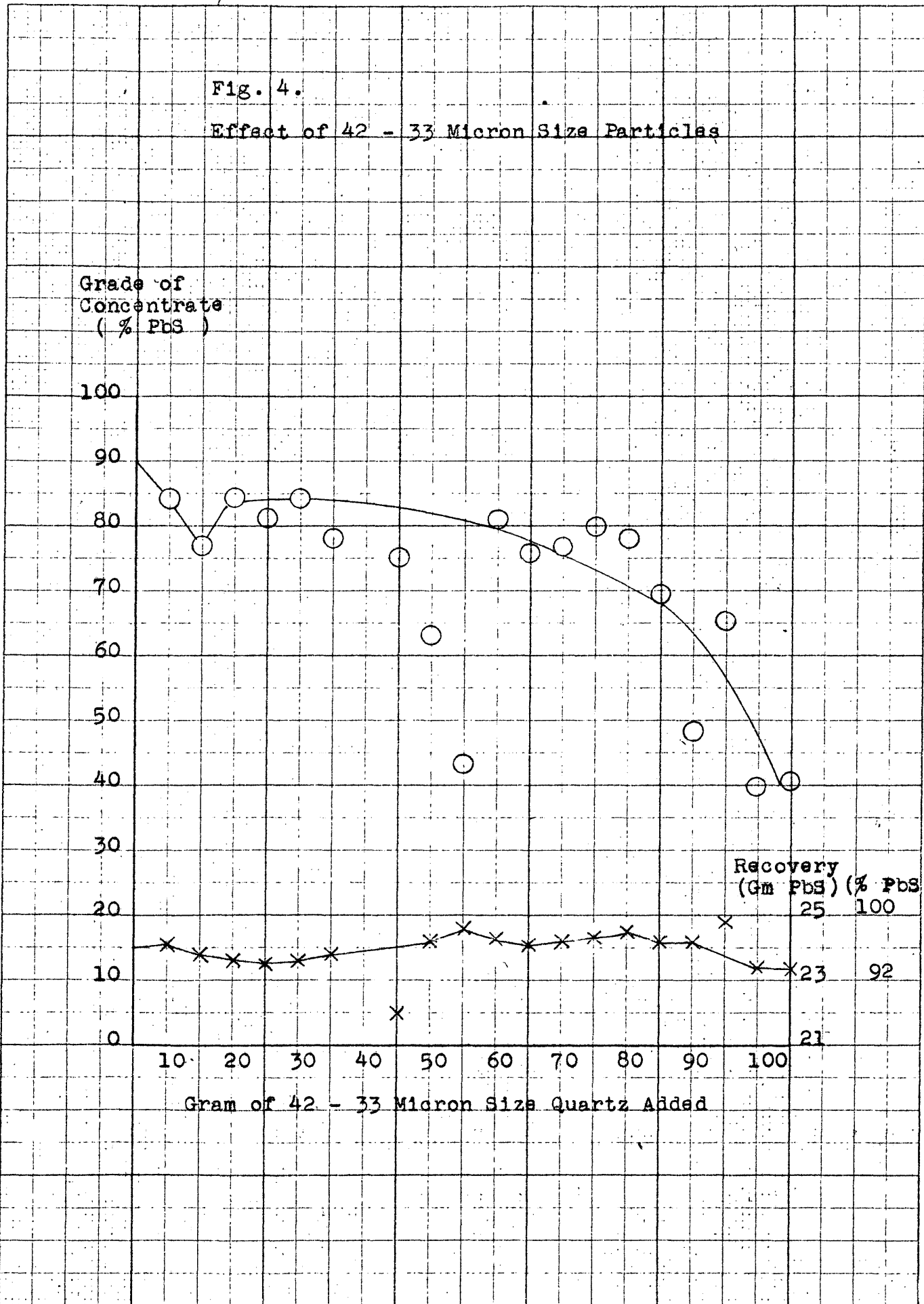


Fig. 5.
Effect of 33 - 22 Micron Size Particles

Grade of Concentrate
(% PbS)

100

90

80

70

60

50

40

30

20

10

0

10

20

30

40

50

60

70

80

90

100

Gram of 33 - 22 Micron size Quartz Added

Recovery
(Gm PbS) (% PbS)

25

100

23

92

21

0

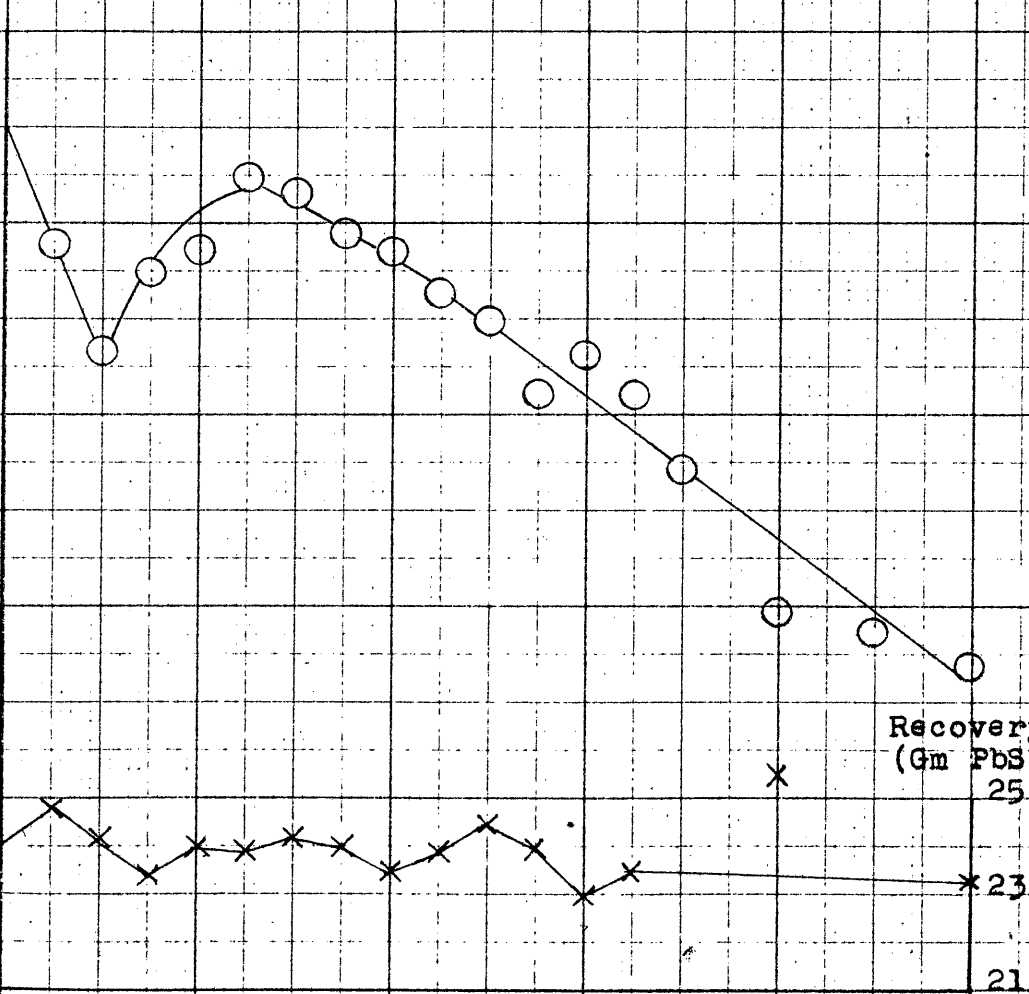
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Fig. 6.

Effect of 22 - 14 Micron Size Particles

Grade of Concentrate
(% PbS)

100
90
80
70
60
50
40
30
20
10
0



Recovery
(Gm PbS) (% PbS)
25 100

Gram of 22 - 14 Micron Size Quartz Added

*23 92
21

Fig. 7.

Effect of 14 - Fractional Micron Size Particles

Grade of Concentrate
(% PbS)

100

90

80

70

60

50

40

30

20

10

0

Recovery
(Gm PbS) (% PbS)

25

100

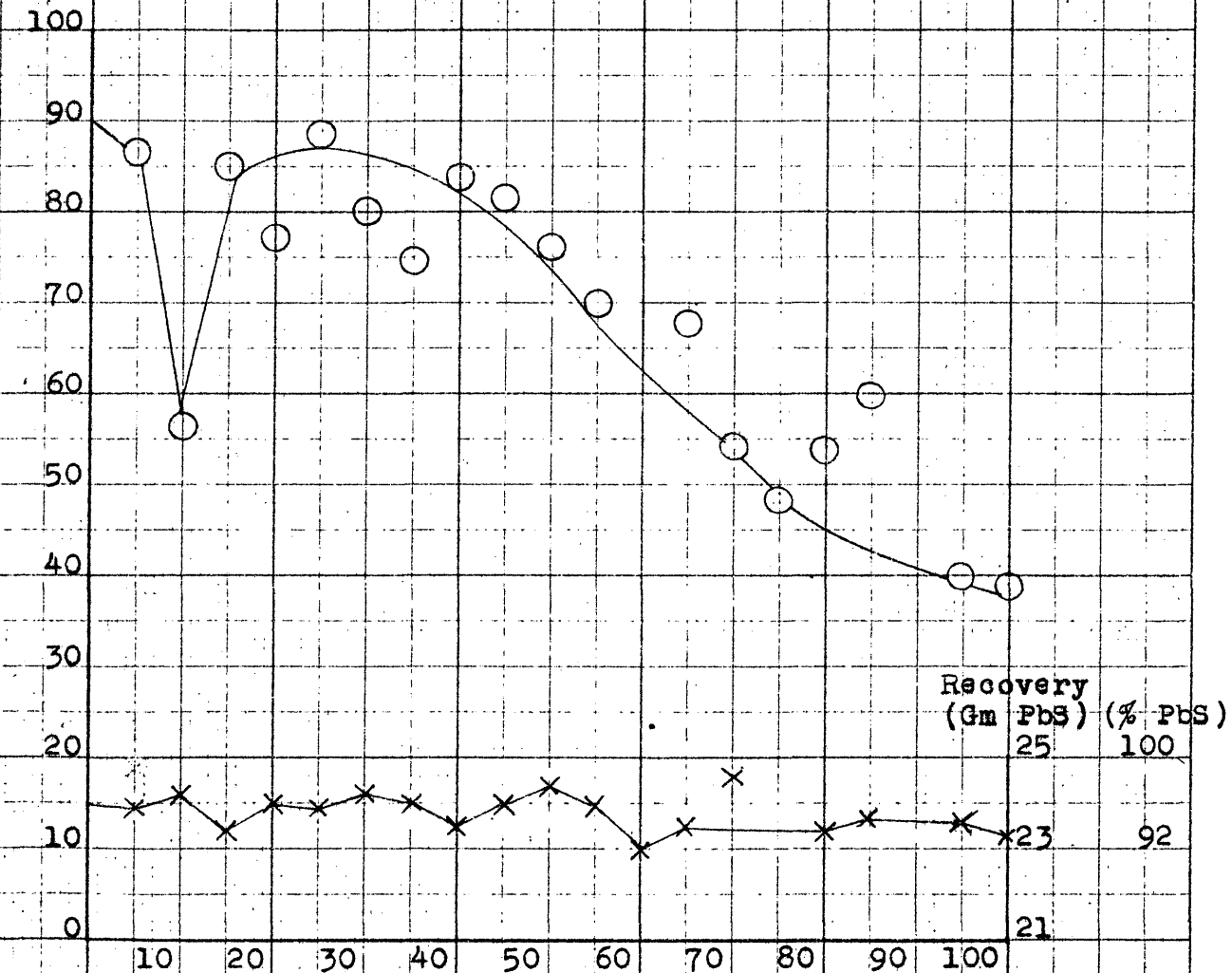
23

92

21

Gram of 14 - Fractional Micron Size Quartz Added

10 20 30 40 50 60 70 80 90 100



Observations

1. Both the floated and non-floated galena are not coated with fine particles.
2. Flocculation of the gangue mineral particles could be observed, though not to a great extent.
3. As the size of the added fine particles becomes smaller, the bubbles formed in the froth become larger, tougher, muddy-looking, and more difficult to break up. The largest bubble was estimated to be approximately 1 inch in diameter, with a life of more than 30 seconds before breaking up.
4. It was obvious that the layers of the froth consisted of various sized bubbles, with large dirty-looking ones on the top layer, and small, even, clear ones on the bottom of the froth.
5. The pH value of the pulp, even in the case of 100 grams of the minus 14 micron range particles, was found to remain neutral. The possibility of the formation of the silicic acid between quartz and water as expressed by Taggart, Taylor, and Knoll¹⁰ is doubtful.
6. The fine particles of galena and quartz formed by the mechanical attrition of the WEMCO flotation machine only colored the filter paper black; however, beyond the point of weighing.
7. Because of the one error made during the hundred experiments by adding the pine oil only without collector Z-5, it was found that many fine particles floated in the froth.

8. As the means of skimming is mainly manual, and the human operations cannot be precisely controlled, the weight of the concentrate is bound to show some slight variations.

CONCLUSIONS

1. Whatever the amount and size of the fine quartz particles, virtually all of the galena could be recovered with no large variation in percentage of recovery. This suggests the fact that the consumption of reagent by "slime" is not serious in sulphide flotation.
2. Graphs 1 and 2 disclose that the grade of the concentrate does not change. It can be said, therefore, that the quartz particles between the size range of 200 mesh and 325 mesh have no noticeable effect on the grade of the concentrate.
3. The effect of the 58 to 42 and 42 to 33 micron size particles on the grade of the concentrate is noticeable in the gradual change in Graphs 3 and 4, mainly in lowering the grade of the concentrates.
4. From Graphs 5, 6, and 7, it is observed that the grade of the concentrate changes sharply when 35 grams of the fine quartz particles in the size range from 33 microns down to smallest sizes present are added.
5. In observing the curves indicated by the graphs, the uniformity of the appearance of the small concave portion at the beginning of each curve was unlooked for. So far no explanation has been offered for this phenomenon.
6. The recovery of the fine quartz particles in the concentrate may be partially explained by the lesser settling velocity of these particles, which causes their overflowing

"mechanically" between bubble walls and thus lowering of the grade of the concentrate.

7. If the slime-coating effect does exist in this experiment, 100 grams of minus 14 micron size quartz particles will have sufficient surface to coat completely, to a thickness of several layers of the surface areas, the 25 grams of minus 65 plus 100 mesh galena particles. However, the result shows that ^{23.1}22.7 grams out of 25 grams galena still floated. This indicates that there is no appreciable quartz particle coating the galena and thereby preventing its flotation.
8. The presence of fine particles lowers the surface tension of the small bubbles, and causes coalescing into large bubbles; furthermore, the fine particles will also increase the viscosity of the bubble film. The preferential adherence of small-size particles to bubbles may be due to high viscosity of the bubble film, which is the large surface area for adsorption, or, according to Taggart^{11/}, due to the large contact angle resulting from large bubble volume.
9. The phenomenon that the fine particles of the gangue mineral float more readily than larger particles can be explained by the fact that aggregates of the gangue mineral particles once having been carried mechanically into the froth cannot slide freely within the liquid channels, and remain in the froth to be skimmed off with the galena particles.

10. Amounts of xanthate collectors added have little or no effect on the attachment of fine particle sizes of quartz gangue to air bubbles. The effect of frothers is much more important.

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