

THE EFFECT OF COPPER SULPHATE
ON THE CATIONIC FLOTATION OF SPHALERITE

Made to
The Department of Metallurgy
of
The Colorado School of Mines

By
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Golden, Colorado
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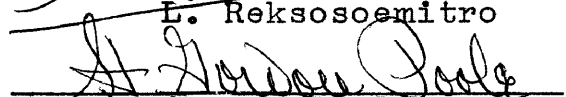
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INTRODUCTION

The introduction to this paper is in three parts which illustrate some of the background to the problem:

Statement of the Problem

Mechanism of Collection

Significance of Contact Angle
in Flotation

Statement of the Problem

The investigation on which this paper is prepared has a twofold purpose: (1) to determine the effect of copper sulphate on sphalerite when floated with an amine-type collector and (2) to compare the result with the one obtained when an xanthate-type collector is used.

The conclusions derived from this investigation may not, in themselves, be of primary importance for they are examples of steps that can be taken in the investigation of a general behavior of sulphide ores in contact with cationic collectors.

The work reported in this paper is designed to investigate the effect of copper sulphate on sphalerite ore by the use of primary long-chain-amine-salt collectors. Primary long-chain-amine collectors were chosen, because they are less expensive than the short-chain-amine or the secondary-amine, tertiary-amine, and quarternary-amine.

Two methods of investigation were followed: flotation of the ore and determination of the contact angle on a mineral specimen. Conditions for both methods were kept the same, so that a comparison could be obtained from the results.

From the flotation method the percentage recovery at various pH can be obtained for the ore both with and without pre-treatment with copper sulphate.

From the contact-angle method, the contact angle of the mineral specimen at various pH can be obtained both with and without preconditioning with copper sulphate.

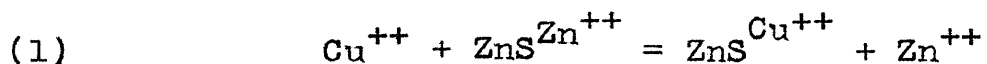
By comparing the data from both methods, one can determine whether activation or depression occurs. One can also see how closely the contact-angle curves resemble the percent-recovery curves. An increase in recovery or in contact angle determines the degree of activation.

Mechanism of Collection

The behavior of anionic collectors at sulphide-mineral surfaces may be interpreted on the basis of an anion exchange. Treatment with a xanthate solution affords an opportunity for exchange between the anionic group and the xanthate.

However, experiments conducted by Gaudin (1930 p. 419) showed that unactivated sphalerite did not abstract ethyl xanthate from solution and thus could not be floated with the reagent.

If a copper salt is added to a sphalerite pulp and conditioned with the mineral for a few minutes, the mineral is changed in its behavior toward the collector, which is now much more effective. The copper is abstracted by sphalerite in exchange for zinc, the over-all reaction being represented by



which is substantiated by Ralston, King, and Tartaron (1930, p. 397) and Gaudin (1930, p. 420).

In the case of cationic collectors, a cation exchange will occur between the aminium ion and a cation on the mineral surface.

Significance of Contact Angle in Flotation

The primary requisite for flotation is a sufficient attraction between mineral and air so that air is at least partly to replace water at the mineral surface. If replacement of water by air is impossible, flotation is impossible.

In the study of the attraction between air and mineral, the measurement of contact angle is generally accepted. If the angle of contact, measured across the solution, is zero deg, the mineral is lyophilic; if it is 180 deg, the mineral is lyophobic. The contact angle can be used in deriving an estimate of the tenacity of sticking between mineral and air, so that if the angle can be measured satisfactorily, the primary tendency to float can be evaluated.

Any surface such as that between water and air resists extension. It is this interfacial tension which tends to make small masses of water in air take on a spherical shape, and small masses of air in water become bubbles, because the sphere has less surface per unit volume than any other form. The relative values of the interfacial tension may be determined by the contact angle (angle formed between interfaces), when three or more phases are in contact and at equilibrium.

When a solid particle is attached to a bubble, the force of gravity and the agitation tend to dislodge the particle from the bubble. If the contact angle is small, the liquid will advance over the surface of the solid, and the forces

holding the solid and the bubble together are weak. If the contact angle is large, the solid particle attaches itself to the bubble and there is loss in surface energy. This loss in energy is a measure of the lyophobic properties of the solid phase and therefore an indication of the floatability. This loss represents the work necessary to separate the air from a unit surface of solid. Because the loss in energy is a function of the contact angle, a contact-angle measurement can indicate the floating tendency of the mineral.

This paper is presented under the following main headings:

- Experimental Procedure
- Experimental Data
- Discussion of Result
- Experimental Limitations
- Conclusions

SUMMARY

In an effort to determine the effect of copper sulphate on sphalerite treated with a cationic collector, flotation tests and contact-angle tests were performed.

A 50-g sample was floated each time. Except for the pH, everything was kept constant. Flotation tests were performed for pH ranging from 1 to 12. Activation was shown when the sample was pre-conditioned with copper sulphate, using an anionic as well as a cationic collector.

Contact-angle tests under similar conditions on the mineral specimen also showed a definite increase in angle when pre-conditioned with copper sulphate for both cases.

EXPERIMENTAL PROCEDURE

The description of the experimental procedure followed in this investigation is in two parts:

Flotation-test Method

Contact-angle-test Method

Flotation-test Method

The description of the flotation cell set-up and the experimental procedures followed are discussed as the following topics: Apparatus, Ore Preparation, Reagents, and Flotation-test Procedure.

Apparatus: The flotation cell, of a pneumatic type, was similar to that described by Professor Cooke (Chang, Cooke and Huch, 1953, p. 1283). In addition, a mercury manometer was installed to regulate the compressed air, and a set of flasks was used as a filter to free the air from oil and contaminants.

The cell consisted of a 350-cc-capacity Buchner fritted-glass funnel with medium-porosity frit. Air was admitted through the bottom of the cell and controlled by a valve. Admission of air alone did not give sufficient agitation to keep all the material in suspension; hence, supplemental mild agitation, provided by a motor-driven glass stirring rod, was used in the cell. A wooden sleeve was fitted to the neck of the cell to facilitate the collection of the froth. The complete assemblage is shown in Fig. 1.

The froth flows from the cell into a Buchner funnel where the froth is filtered and the filtrate is transferred to the solution reservoir by suction. This solution, then available for re-introduction to the cell when desired, eliminates the necessity of adding water during a test.

Ore Preparation: Jig concentrates from the Tri-State district were used as raw material. Besides sphalerite, these concentrates contained small amounts of galena, pyrite, and siliceous material. The commercial jig concentrates were purified by grinding in a pebble mill to pass a 100-mesh laboratory sieve and tabling. This operation removed most of the galena, pyrite, siliceous gangue, and slime. After being tabled the ore was deslimed again, dried at a low heat over a gas hot-plate, and put through a magnetic separator. Most of the slime and the iron contaminants were removed after this operation. All machines and containers

Figure 1



The Flotation Cell with Its
Auxiliary Equipment.

1. Buchner fritted-glass funnel.
2. Stirrer with glass rod.
3. Wooden sleeve.
4. Buchner funnel.
5. Solution reservoir.
6. Vacuum line.
7. Hg manometer.

were carefully cleaned before use, to prevent contamination of the mineral by grease and other contaminants.

An analysis of the prepared ore is given in Table 1.

Table 1

Percentage Chemical Analysis of Purified Mineral

Zn	65.4
S	29.25
Fe	1.9
Pb	0.23
Cu	0.03
CaO	0.30
Insol.	<u>0.73</u>
Total	97.84

Although the presence of Cu is not desirable, the small amount present will not interfere with our purpose of getting a comparative result.

The sizing above 325-mesh was done by means of screens following the ratio of the square root of 2. The minus 325-mesh material was sized by settling in beakers on the basis of calculated settling velocity. The minus 325-mesh sizing analysis was therefore only approximate. A sizing analysis is given in Table 2.

Table 2
Sizing Analysis of Purified Mineral

Diameter Range (microns)	Screen Size (mesh)	Weight (percent)
-147 + 104	-100 + 150	37.0
-104 + 74	-150 + 200	28.4
- 74 + 43	-200 + 325	23.8
- 43 + 20	-325 + 750	10.3
- 20	-750	0.5*

(*) By arithmetical difference.

Reagents: Potassium ethyl xanthate and Frother 70 are products of the American Cyanamid Company. Potassium ethyl xanthate was chosen, because it has little tendency to float sphalerite (Gaudin, 1930, p. 418). Frother 70 is an alcohol-type frother, which has almost no collecting power.

Coco Amine, Armac CD, is a product of Armour Chemical Division, Armour and Company. This collector is an acetate salt of a primary long-chain amine, which is composed mainly of C₁₂ with smaller amounts of C₈ through C₁₈ amines.

Tallow Amine, Armac TD, is a product of Armour Chemical Division, Armour and Company. It is also an acetate salt composed of mainly C₁₈ amine and with smaller amounts of C₁₄ through C₂₂.

Both amines were chosen because they generally are used for floating non-metallic ores.

Copper sulphate was used as the activator, and NaOH and HCl were used as the pH-regulators.

Flotation-test Procedure. Each charge to the flotation cell consists of 50 g of ore and 330 cc of distilled water. The mixture was agitated for 1 minute to assure perfect contact of the ore with the solution. After the pH was adjusted, a desired amount of collector was added and the mixture was agitated for 3 minutes. The frother was poured into the cell and the froth removed until it was free of mineral. Flotation was allowed to proceed for 3 minutes.

When copper sulphate was used, it was introduced into the cell right after the distilled water was added. An additional agitation of the ore with the copper sulphate was allowed for 1 minute.

Flotation tests were performed at room temperature and the air was admitted at a gauge pressure of about 11 psi. Tests were performed for 3 kinds of collectors at pH ranging from 1 to 12, using ore samples with and without pre-treatment with copper sulphate. All other variables were kept constant during the entire flotation operation.

Both concentrates and tailings were dried at a low heat over a gas hot-plate and weighed.

All pH measurements were done with a Beckmann pH-meter.

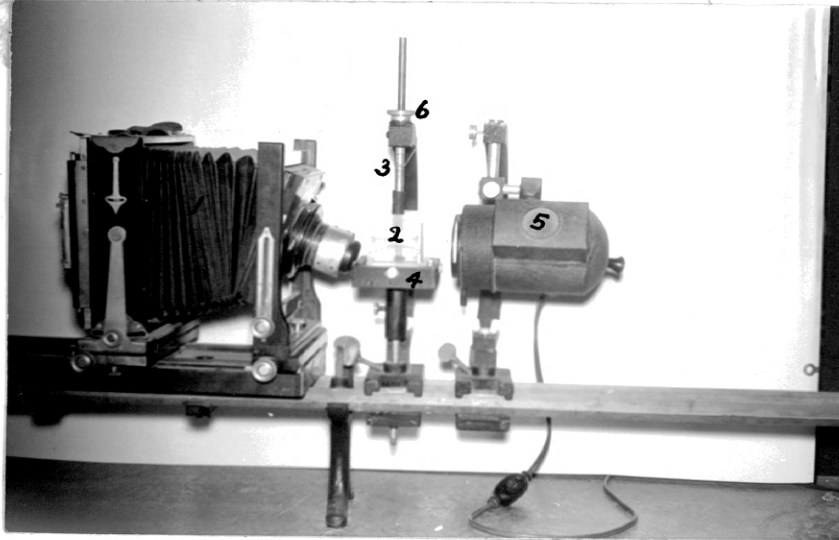
Contact-angle-test Method

The description of the contact bubble machine and the experimental procedures followed are discussed under the following headings: Apparatus, Sample Preparation, Reagents, and Experimental Procedure and Angle Measurement.

Apparatus: The bubble machine was similar to that designed by Taggart, Taylor, and Ince (1930, p. 288). The bubble machine consisted essentially of a camera so set as to record on ground glass or a photographic plate the performance on a particle surface of a captive air bubble when both particle and bubble were immersed in a liquid in the container. This container is a plate-glass cell, illuminated by a lamp. A bubble holder was attached to a frame and could be screwed up or down. The bubble holder was a glass tube, and was so held as to project down into the cell in the upright position. The mechanical stage on which the container was placed could be moved up or down.

The complete assemblage is shown in Fig. 2. Operation of the bubble machine consisted in filling the cell with the liquid of which the collecting effect was to be tested, placing on the bottom of the cell the particle to be tested, immersing the tip of the bubble holder below the surface of the liquid, and forming therein a bubble of desired size by means of a curved medicine dropper; then, by means of a screw, bringing the bubble down until it made contact with

Figure 2



The Bubble Machine

1. Camera.
2. Container.
3. Bubble holder.
4. Mechanical stage.
5. Lamp.
6. Screw to move the bubble holder up or down.

the upper surface of the particle. The contact of the bubble and the mineral could be watched on the ground glass of the camera.

Sample Preparation: Several pieces were selected for their purity and lack of cracks and faults. Two opposite surfaces in the long dimension of each sample were ground flat and reasonably parallel. Several stages of rough grinding were done with suitable grinding material and water. The next step was to polish the surface on a silk lap with alumina suspended in distilled water. The specimen being polished was then transferred into a beaker of which the bottom was covered with clean filter papers and which contained distilled water. Further handling of the particle was done with thoroughly cleaned forceps.

Reagents: The same kind and strength of reagents as those used for flotation were used for the tests. The potassium ethyl xanthate was introduced at a strength of 36.2 mg per liter and copper sulphate, Coco Amine, Tallow Amine, and Frother 70 were added separately at a concentration of 14.5 mg per liter. Throughout the entire test 66 cc of distilled water was used each time.

Experimental Procedure and Angle Measurement: Before each test the sample was rubbed gently on the filter paper at the bottom of the beaker to remove grinding mud from the polished surface. It was then tested in distilled water for

zero deg contact angle.

The solution to be tested was made up in the same manner as the one followed in flotation. First 66 cc of distilled water was poured into the container and the pH was adjusted. The sample was then put in the container and shaken for 1 minute to assure contact of the mineral surface with the solution. In the case where copper sulphate was used, the reagent was added right before the pH was adjusted. Pre-treatment of the mineral with this reagent was allowed to proceed for 1 minute. The collector was then added and the particle shaken for 3 minutes. The frother was then introduced and the pH was recorded. The specimen was now ready for testing.

The next procedure applied was the one adopted by del Giudice (1936, p. 294). The particle was placed with the polished surface up. The container was set on the mechanical stage, with the ground-glass side toward the source of light. The tip of the bubble holder was kept below the surface of the liquid in the container and a bubble was allowed to form on it by means of a curved medicine dropper. The bubble holder was then lowered until the lower surface of the bubble almost made contact with the polished particle surface. The bubble was forced down onto the particle surface and was kept pressed for 1 minute. The bubble was then raised very slowly until the line of three-

phase contact just began to contract. The cell stage was tapped gently until the bubble came to equilibrium. This entire performance could be watched on the ground glass. With a transparent protractor, the angle was measured on the ground glass of the camera. The left and the right angle were measured and the medium was taken for each reading. An average of three readings was taken for each sample at each pH to give the contact angle.

Contact angles were measured for the mineral in the collectors with and without pre-treatment with copper sulphate at pH ranging from 1 to 12. The minerals were tested at room temperature. The pH was measured with a Beckman pH-meter.

EXPERIMENTAL DATA

The data are divided into three parts:

Preliminary Investigation

Flotation Tests

Contact-angle Tests

Preliminary Investigation

The object of this investigation is to determine the quantity of each reagent to be used during flotation. Because an insufficient amount of reagent causes a lower recovery, the reagent does not give a clear picture of its response to the ore. In the case of the amines, an overdose of the reagents will result in a double-layer collector effect (Armour Chemical Division, 1956). The second layer of the Armac coating will orient the water-avid portion of the molecule away from the mineral. This effect will result in a decrease in recovery.

Potassium ethyl xanthate was used in the amount of 0.5 lb per ton (Gaudin, 1930, p. 418).

Frother 70 was used in the amount of 0.2 lb per ton (American Cyanamid Company, 1956).

Copper sulphate was used at the strength of 0.2 lb per ton (Gaudin, 1957, p. 310).

Coco Amine and Tallow Amine were added in the amounts of 0.2 lb each per ton. These amounts were obtained from a series of tests. Tables 3 and 4, and Fig. 3 show the data of the tests.

Table 3

The Effect of Coco Amine Concentration on the Flotation of Sphalerite (minus 100 mesh) at pH 7 ± 0.2

Amount (lb/t)	Concentrate (g)	Recovery (percent)
0.02	8.064	16.12
0.05	47.941	95.81
0.10	49.540	99.0
0.20	49.582	99.5
0.25	49.580	99.5

The investigation was stopped here because a 100-percent recovery could not be obtained. The tests recorded in Table 4 were stopped at 98.2-percent recovery because adding more reagent did not give an appreciable increase of the concentrate. Flotation with Frother 70 only with no collector added gave a recovery of 4.67 percent.

Table 4

The Effect of Tallow Amine Concentration on the Flotation of Sphalerite (minus 100 mesh) at pH 7 ± 0.2

Amount (lb/t)	Concentrate (g)	Recovery (percent)
0.02	20.037	40.0
0.05	32.040	64.0
0.10	47.809	95.5
0.20	49.125	98.2
0.25	49.130	98.2

Flotation Tests

Sixty-four flotation tests were made. The experimental flotation data are indicated in Table 5 to Table 10.

Fig. 4 is a plot of pH against percent recovery for potassium ethyl xanthate with and without pre-treatment with copper sulphate.

Fig. 5 is a plot of pH against percent recovery for Coco Amine with and without copper sulphate.

Fig. 6 is a plot of pH against percent recovery for Tallow Amine with and without copper sulphate.

Potassium ethyl xanthate shows an increase in recovery in the acid side. But in all cases, a definite activation (increase in recovery) can be seen after the ore is preconditioned with copper sulphate.

Figure 3

Flotation of Sphalerite (minus 100 mesh) with Frother 70 (0.2 lb per ton) at Various Concentration of Coco Amine and Tallow Amine with No Copper Sulphate at pH 7 ± 0.2 (Tables 3 and 4)

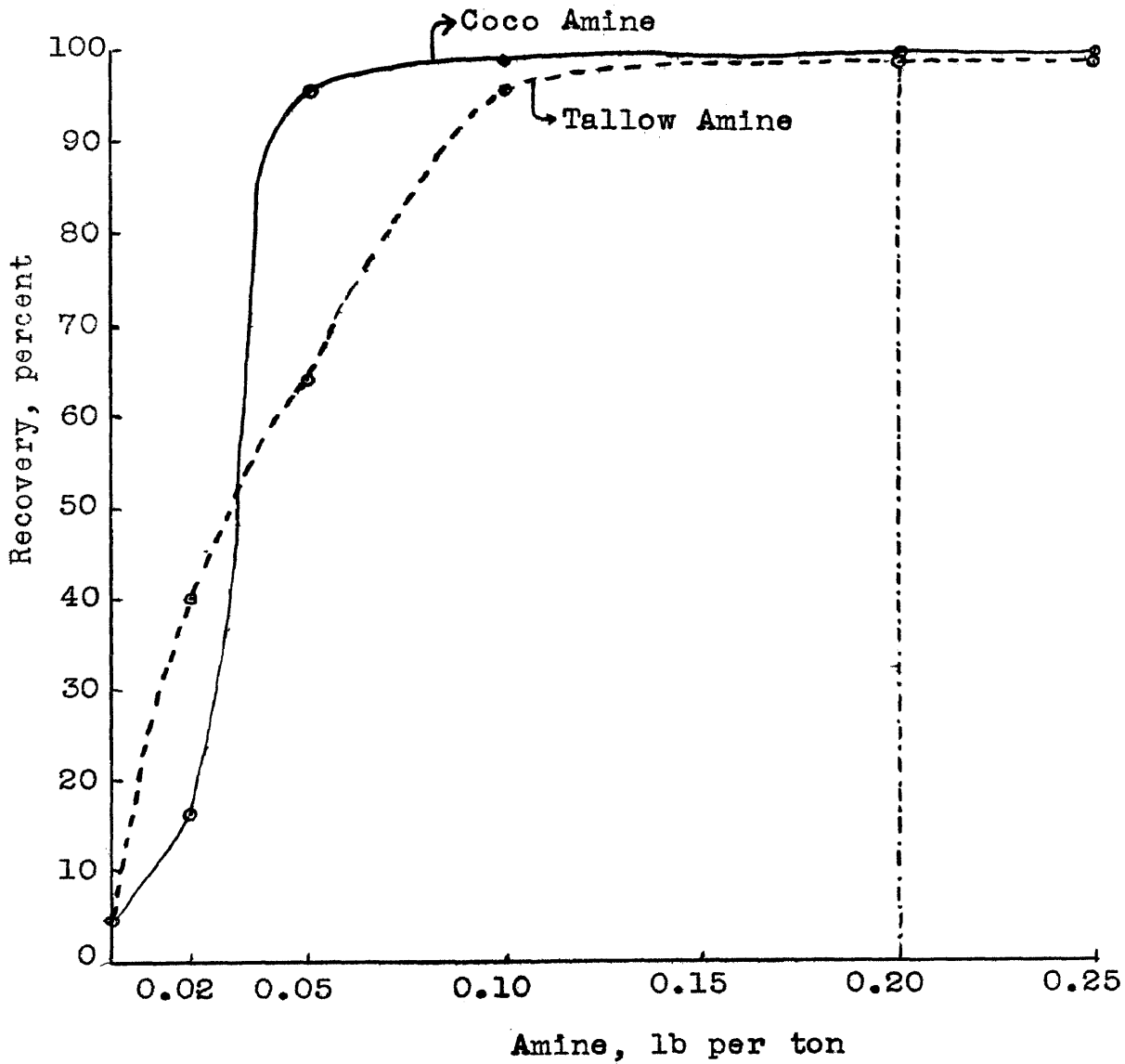


Table 5

Flotation of Sphalerite (minus 100 mesh) with Potassium Ethyl Xanthate (0.5 lb per ton) and Frother 70 (0.2 lb per ton) with No Copper Sulphate at Various pH

pH	Concentrate (g)	Recovery (percent)
1.5	11.085	22.2
2.5	13.175	26.3
3.8	26.319	42.2
5.4	19.558	39.2
6.6	5.327	10.64
7.2*	4.740	9.47
8.4	3.190	6.37
9.5	2.265	4.53
10.5	1.836	3.67
11.4	0.534	1.07
12.0	0.520	1.04

Table 6

Flotation of Sphalerite (minus 100 mesh) with Potassium Ethyl Xanthate (0.5 lb per ton) and Frother 70 (0.2 lb per ton) with Copper Sulphate (0.2 lb per ton) at Various pH

pH	Concentrate (g)	Recovery (percent)
1.6	43.135	86.3
3.3	45.144	90.2
4.6	46.909	93.7
6.9*	48.654	97.4
7.7	46.422	92.7
9.2	45.991	92.0
10.2	44.595	89.3
11.5	43.153	86.3

(*) Indicates the pH of the original solution before adjustment with HCl or NaOH.

Figure 4

Recovery of Sphalerite (minus 100 mesh) with Potassium Ethyl Xanthate (0.5 lb per ton) and Frother 70 (0.2 lb per ton) at Various pH (Tables 5 and 6).

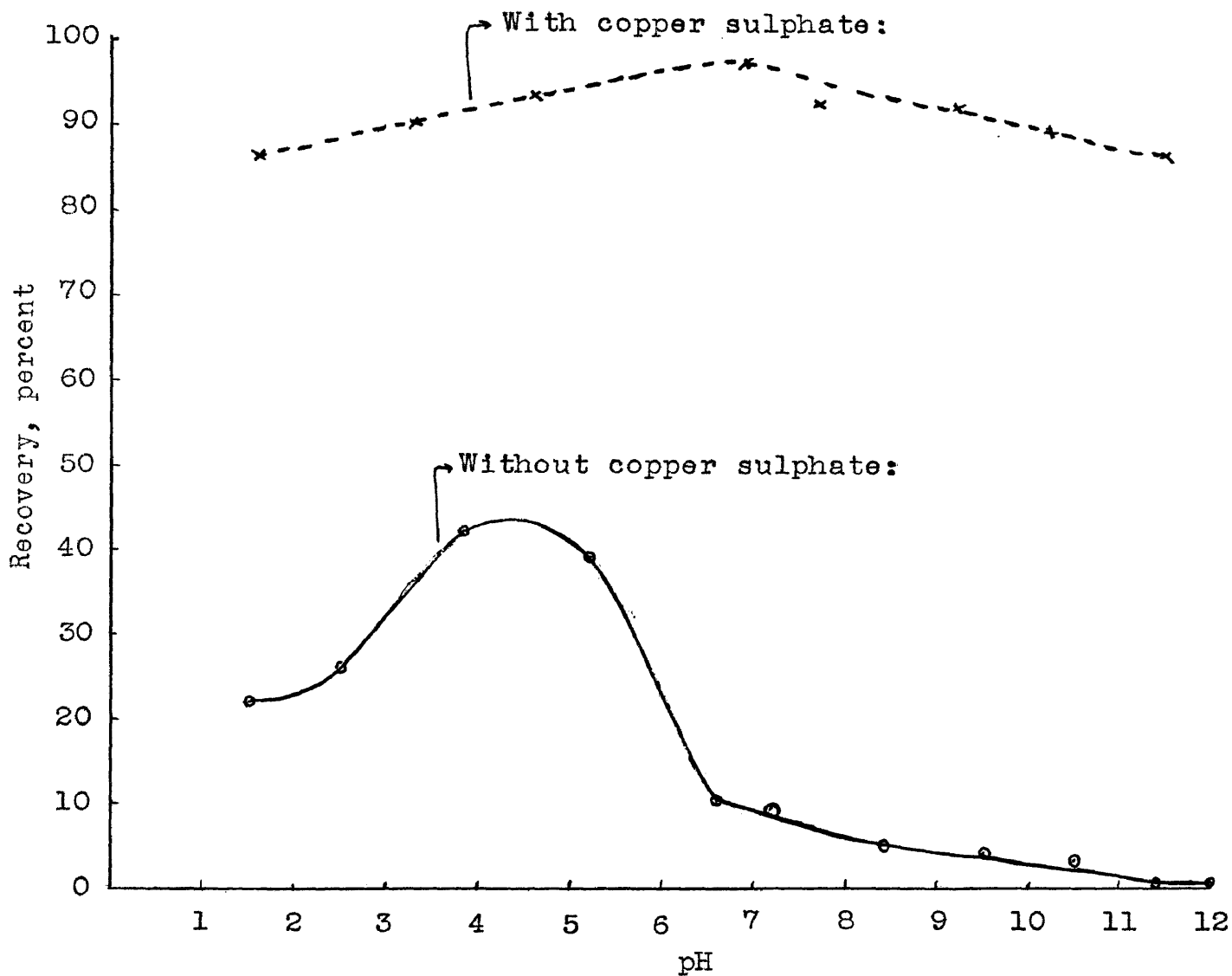


Table 7

Flotation of Sphalerite (minus 100 mesh) with Coco Amine (0.2 lb per ton) and Frother 70 (0.2 lb per ton) with No Copper Sulphate at Various pH

pH	Concentrate (g)	Recovery (percent)
1.6	47.269	94.6
2.6	47.304	94.6
3.8	47.313	94.6
4.1	47.517	94.6
5.1	49.106	98.4
6.8*	49.582	99.4
7.5	49.156	98.5
8.0	49.144	98.3
9.1	49.010	98.0
10.0	47.923	95.8
11.0	47.864	95.8
12.0	46.148	92.2

Table 8

Flotation of Sphalerite (minus 100 mesh) with Coco Amine (0.2 lb per ton) and Frother 70 (0.2 lb per ton) with Copper Sulphate (0.2 lb per ton) at Various pH

pH	Concentrate (g)	Recovery (percent)
0.8	49.378	98.7
2.5	49.804	99.5
4.9	49.750	99.5
6.4*	49.778	99.5
7.0	49.824	99.5
9.4	49.748	99.4
11.5	47.706	95.5

(*) Indicates the pH of the original solution before adjustment with HCl or NaOH.

Figure 5

Recovery of Sphalerite (minus 100 mesh) with Coco Amine (0.2 lb per ton) and Frother 70 (0.2 lb per ton) at Various pH (Tables 7 and 8)

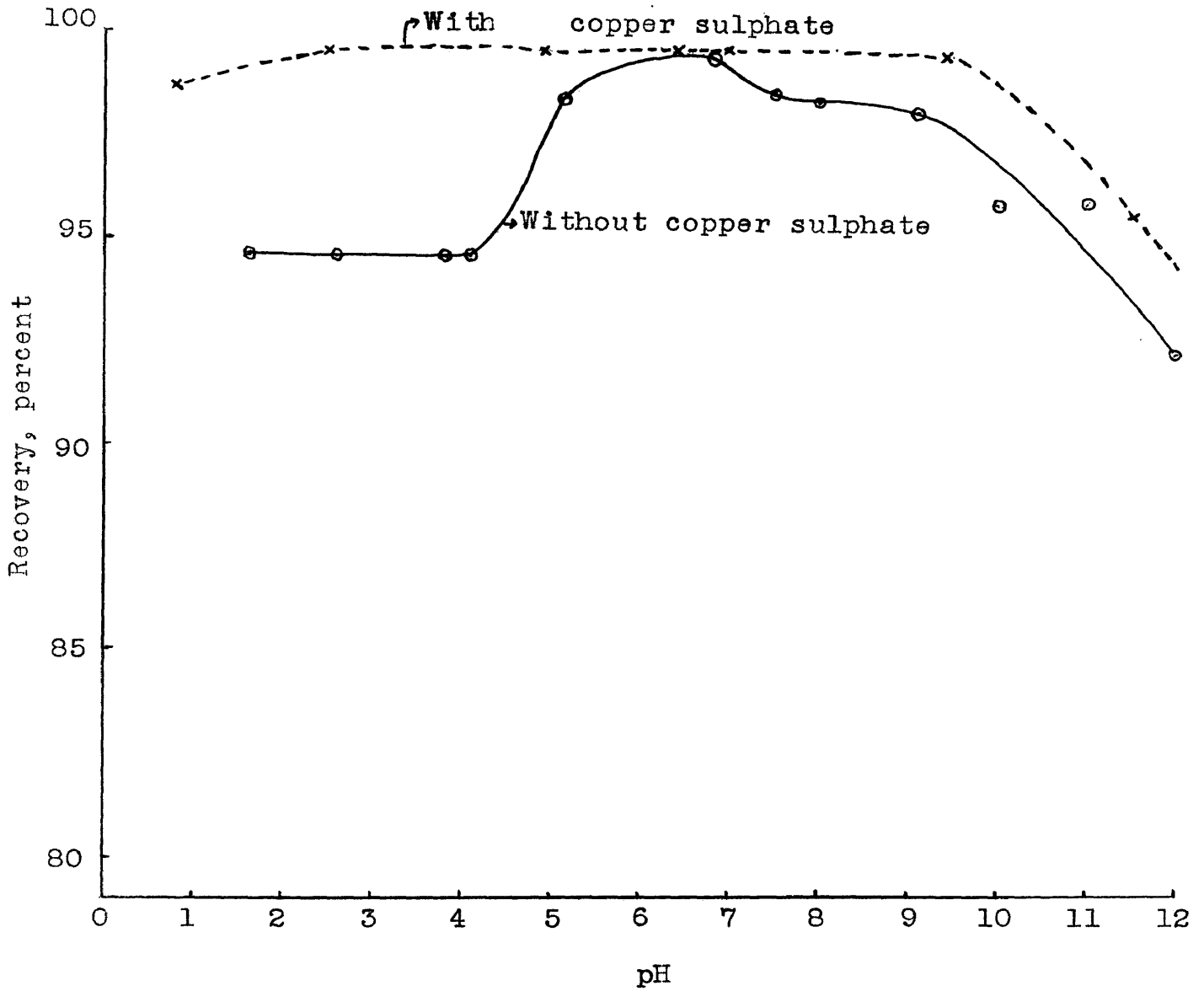


Table 9

Flotation of Sphalerite (minus 100 mesh) with Tallow Amine
(0.2 lb per ton) and Frother 70 (0.2 lb per ton) with
No Copper Sulphate at Various pH

pH	Concentrate (g)	Recovery (percent)
1.7	48.759	97.5
3.2	48.902	97.8
4.7	48.948	97.8
6.9*	49.125	98.2
7.7	49.126	98.2
8.5	49.391	98.7
10.0	48.926	97.8
11.7	46.475	93.0

Table 10

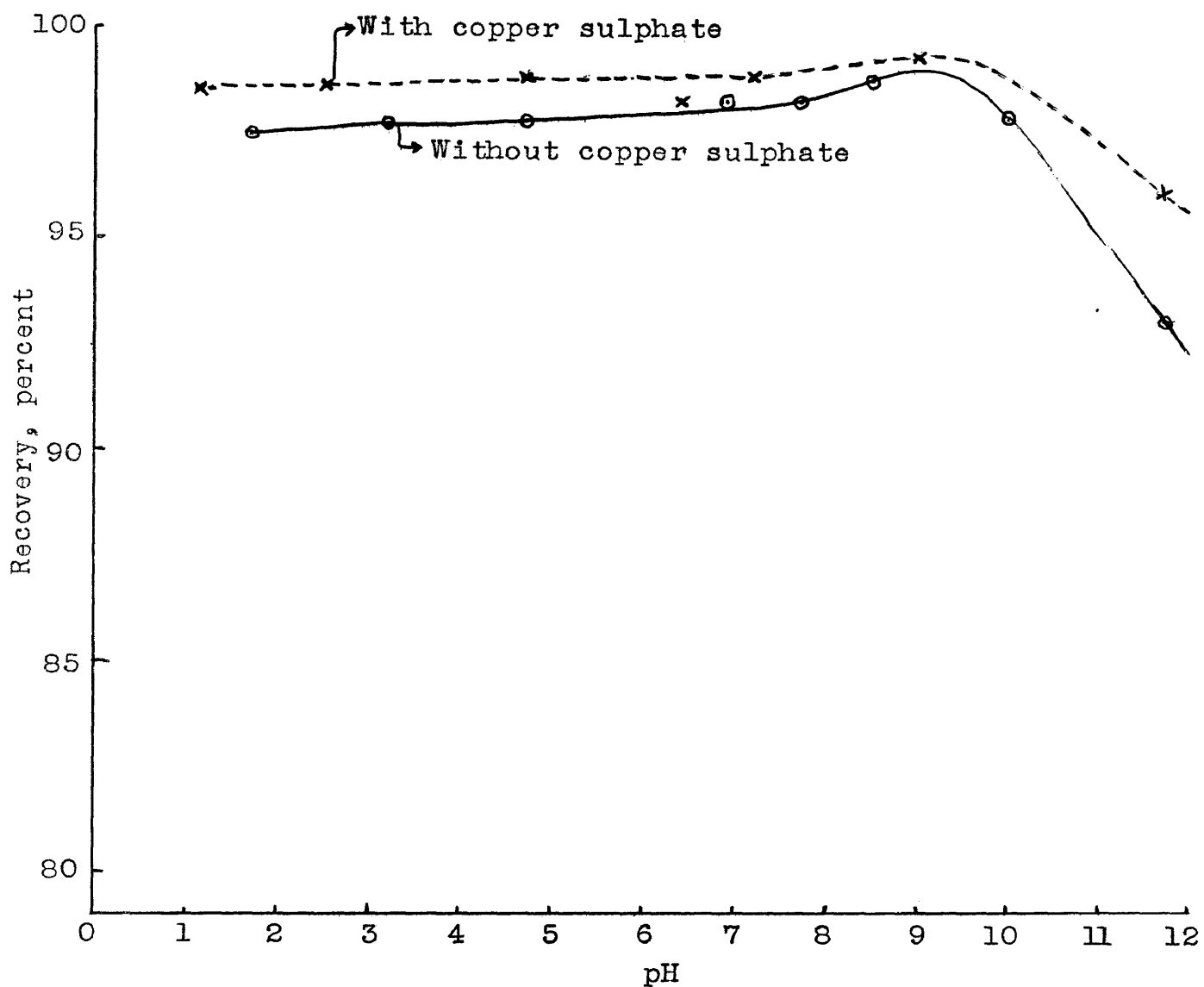
Flotation of Sphalerite (minus 100 mesh) with Tallow Amine
(0.2 lb per ton) and Frother 70 (0.2 lb per ton) with
Copper Sulphate (0.2 lb per ton) at Various pH

pH	Concentrate (g)	Recovery (percent)
1.1	49.240	98.5
2.5	49.302	98.6
4.7	49.464	98.8
6.4*	49.069	98.2
7.2	49.379	98.8
9.0	49.569	99.2
11.7	47.985	96.0

(*) Indicates the pH of the original solution before adjustment with HCl or NaOH.

Figure 6

Recovery of Sphalerite (minus 100 mesh) with Tallow Amine (0.2 lb per ton) and Frother 70 (0.2 lb per ton) at Various pH (Tables 9 and 10)



Contact-angle Tests

A total of sixty-two contact-angle measurements was made. The contact-angle data are tabulated in Table 11 to Table 16.

Table 11 shows contact angles of sphalerite in potassium ethyl xanthate (36.2 mg per liter) and Frother 70 (14.5 mg per liter) without copper sulphate at various pH.

Table 12 shows contact angles of the specimen pre-treated with copper sulphate (14.5 mg per liter) under similar conditions.

In these tables an increase in angle for the whole pH range can be seen for the samples treated with copper sulphate.

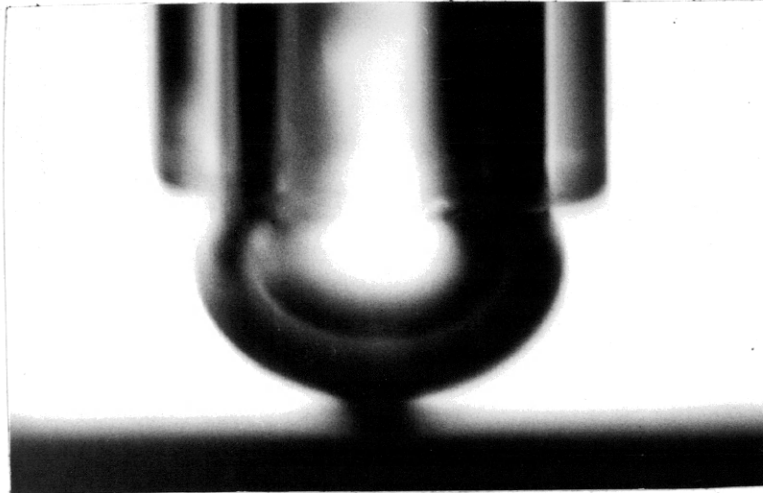
Tables 13 and 14 show contact angles of sphalerite in Coco Amine (14.5 mg per liter) with Frother 70 (14.5 mg per liter) at various pH with and without pre-conditioning of the samples with copper sulphate (14.5 mg per liter). In the case of this collector, copper sulphate also caused an increase in angle for the entire pH range.

Tables 15 and 16 show contact angles of sphalerite in Tallow Amine (14.5 mg per liter) with Frother 70 (14.5 mg per liter) at various pH with and without pre-treatment of the samples with copper sulphate (14.5 mg per liter). Copper sulphate caused an increase in contact angle of the specimen at the various pH.

A plot of pH against contact angle for the data is given in Fig. 13 to Fig. 15.

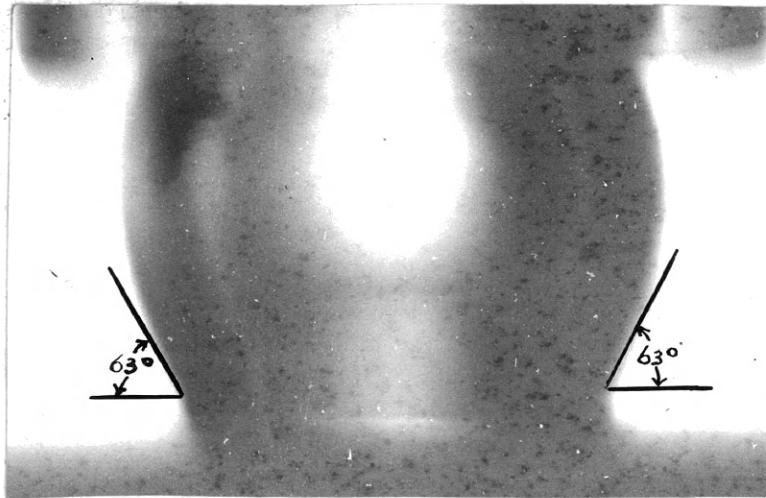
Fig. 7 to Fig. 12 show photographs of bubble in contact with sphalerite in potassium ethyl xanthate, Coco Amine, and Tallow Amine with and without pre-treatment of the mineral with copper sulphate.

Figure 7



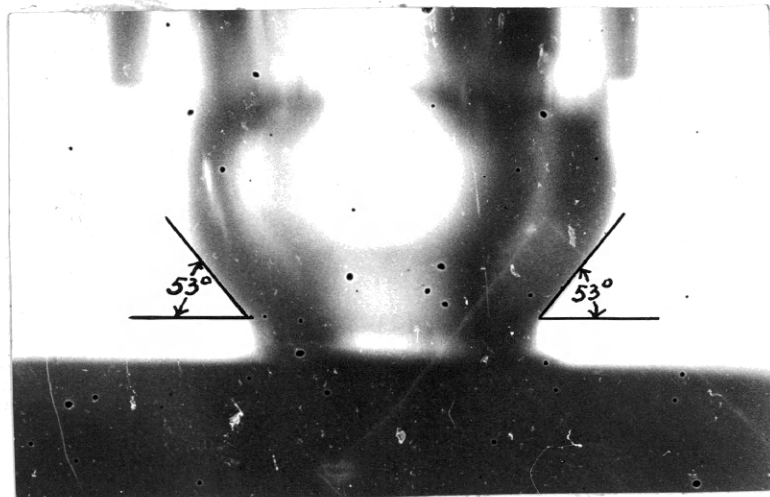
Bubble in Contact with Sphalerite
in Potassium Ethyl Xanthate (36.2
mg per liter) and Frother 70 (14.5
mg per liter) with No Copper Sulphate
at pH 6.5 (Contact Angle zero deg)

Figure 8



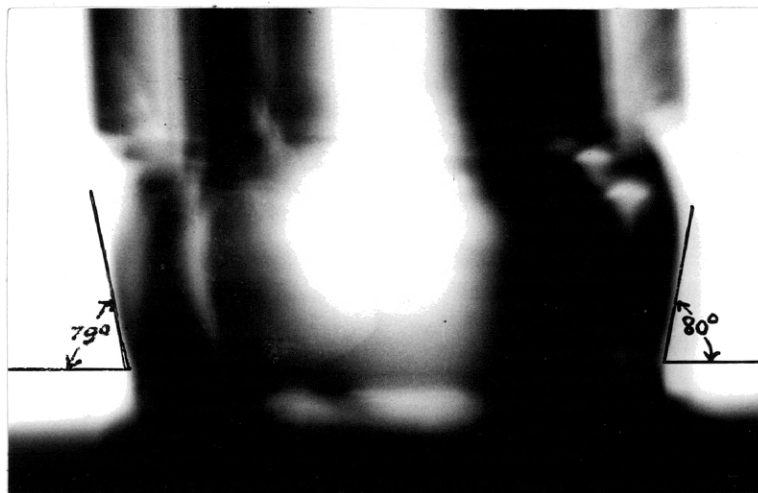
Bubble in Contact with Sphalerite in
Potassium Ethyl Xanthate (36.2 mg per
liter) and Frother 70 (14.5 mg per
liter) with Copper Sulphate (14.5 mg per
liter) at pH 6.3 (Contact Angle 63 deg)

Figure 9



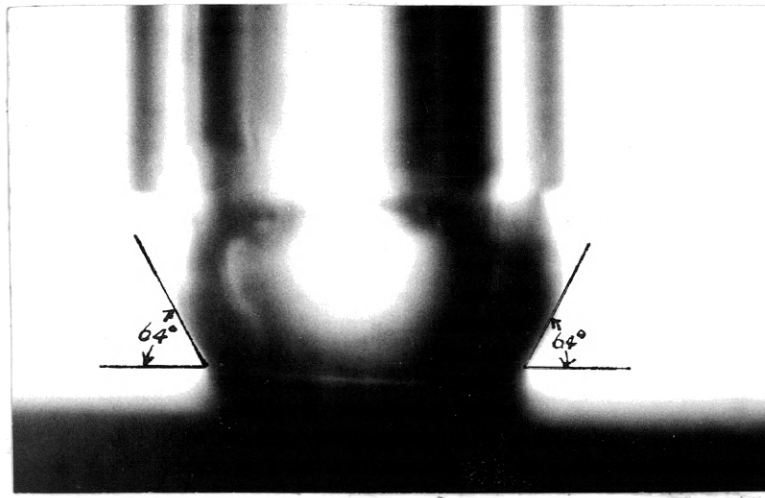
Bubble in Contact with Sphalerite in
Coco Amine (14.5 mg per liter) and
Frother 70 (14.5 mg per liter) with
No Copper Sulphate at pH 12.0
(Contact Angle 53 deg)

Figure 10



Bubble in Contact with Sphalerite in
Coco Amine (14.5 mg per liter) and
Frother 70 (14.5 mg per liter) with
Copper Sulphate (14.5 mg per liter)
at pH 7.7 (Contact Angle 80 deg)

Figure 11



Bubble in Contact with Sphalerite in
Tallow Amine (14.5 mg per liter) and
Frother 70 (14.5 mg per liter) with
No Copper Sulphate at pH 6.1
(Contact Angle 64 deg)

Figure 12



Bubble in Contact with Sphalerite in
Tallow Amine (14.5 mg per liter) and
Frother 70 (14.5 mg per liter) with
Copper Sulphate (14.5 mg per liter)
at pH 6.1 (Contact Angle 75 deg)

Table 11

Contact Angles of Sphalerite in Potassium Ethyl Xanthate
(36.2 mg per liter) and Frother 70 (14.5 mg per liter)
with No Copper Sulphate at Various pH

pH	Angle (deg)
0.3	31
2.5	36
3.6	39
4.1	43
5.3	37
6.5*	11
7.3	9
8.3	8
9.3	0
10.0	0
12.0	0

Table 12

Contact Angles of Sphalerite in Potassium Ethyl Xanthate
(36.2 mg per liter) and Frother 70 (14.5 mg per liter)
with Copper Sulphate (14.5 mg per liter) at Various pH

pH	Angle (deg)
1.0	60
2.5	63
4.4	64
6.3*	63
7.2	63
9.4	63
9.8	63
10.1	63
11.2	61
12.0	59

(*) Indicates the pH of the original solution
before adjustment with HCl or NaOH.

Figure 13

Contact Angles of Sphalerite in Potassium Ethyl Xanthate (36.2 mg per liter) and Frother 70 (14.5 mg per liter) at Various pH (Tables 11 and 12).

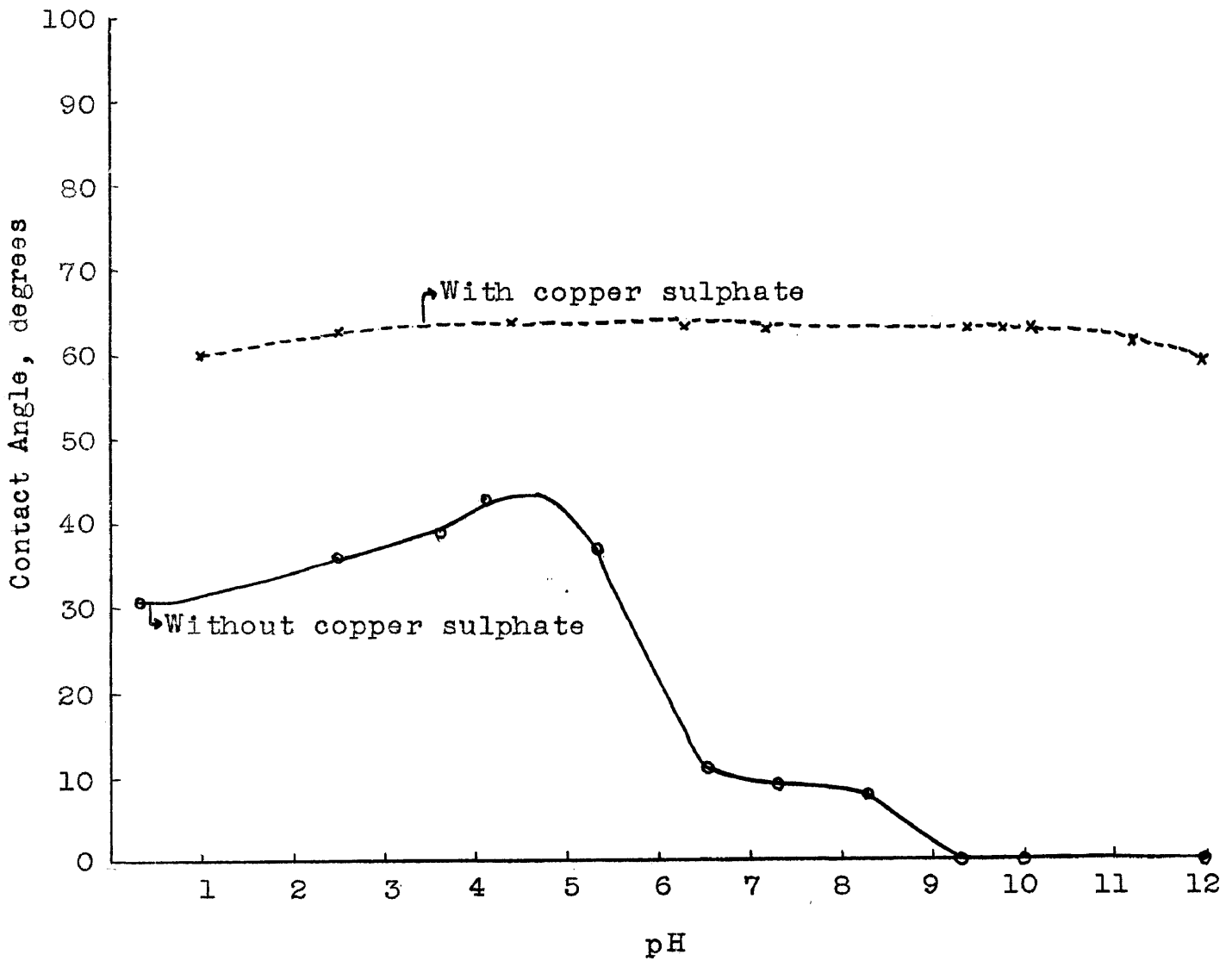


Table 13

Contact Angles of Sphalerite in Coco Amine (14.5 mg per liter) and Frother 70 (14.5 mg per liter) with No Copper Sulphate at Various pH

pH	Angle (deg)
0.9	49
2.4	54
3.1	57
4.1	59
6.2*	78
7.1	66
8.5	63
9.9	57
10.7	55
12.0	53

Table 14

Contact Angles of Sphalerite in Coco Amine (14.5 mg per liter) and Frother 70 (14.5 mg per liter) with Copper Sulphate (14.5 mg per liter) at Various pH

pH	Angle (deg)
0.9	55
2.4	71
4.6	72
4.9	71
5.6	72
6.2*	78
7.7	80
8.3	78
9.9	74
10.4	73
12.0	70

(*) Indicates the pH of the original solution before adjustment with HCl or NaOH.

Figure 14

Contact Angles of Sphalerite in Coco Amine (14.5 mg per liter) and Frother 70 (14.5 mg per liter) at Various pH (Tables 13 and 14)

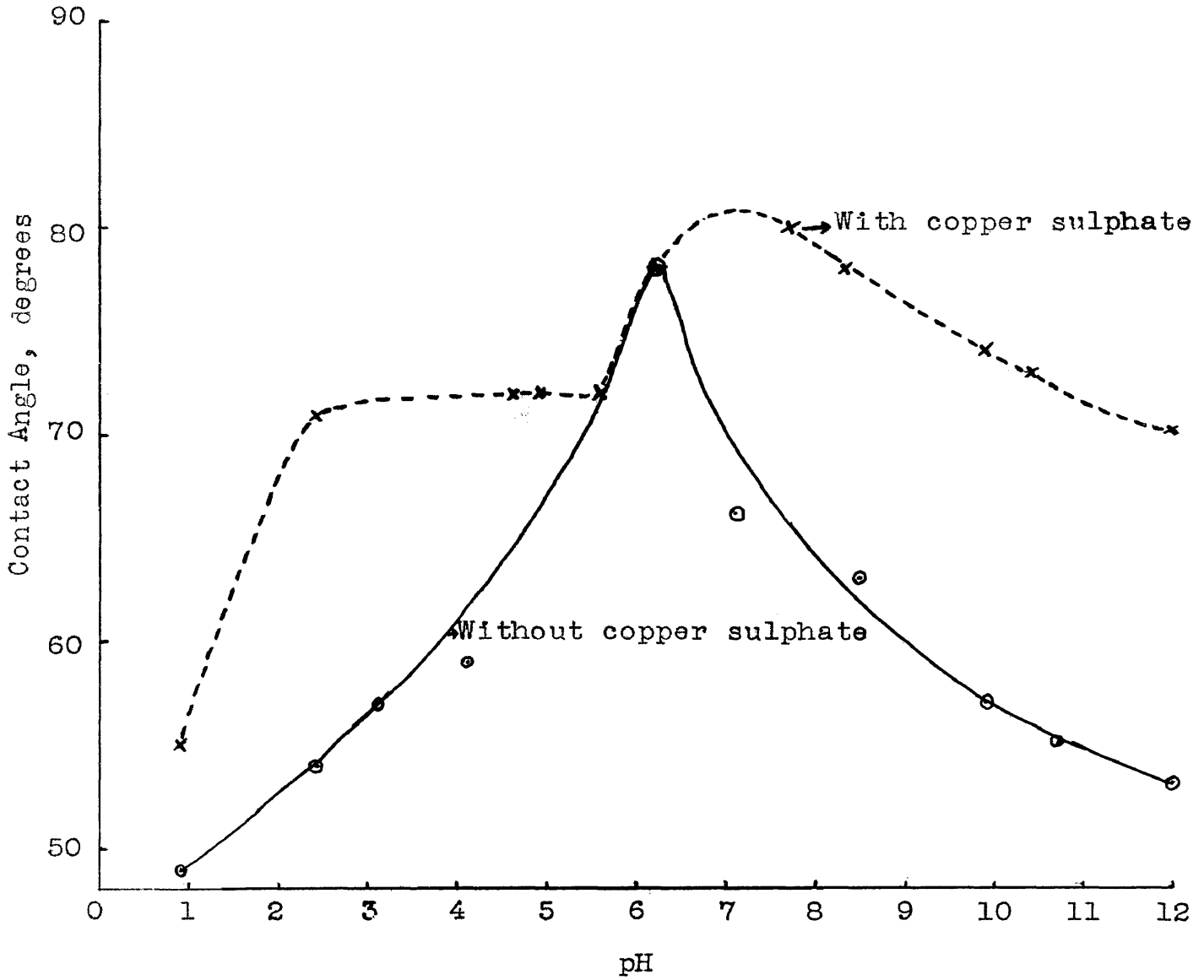


Table 15

Contact Angles of Sphalerite in Tallow Amine (14.5 mg per liter) and Frother 70 (14.5 mg per liter) with No Copper Sulphate at Various pH

pH	Angle (deg)
0.6	53
2.4	60
3.9	64
4.7	64
6.1*	64
7.0	64
8.0	64
9.0	60
11.0	59
12.0	55

Table 16

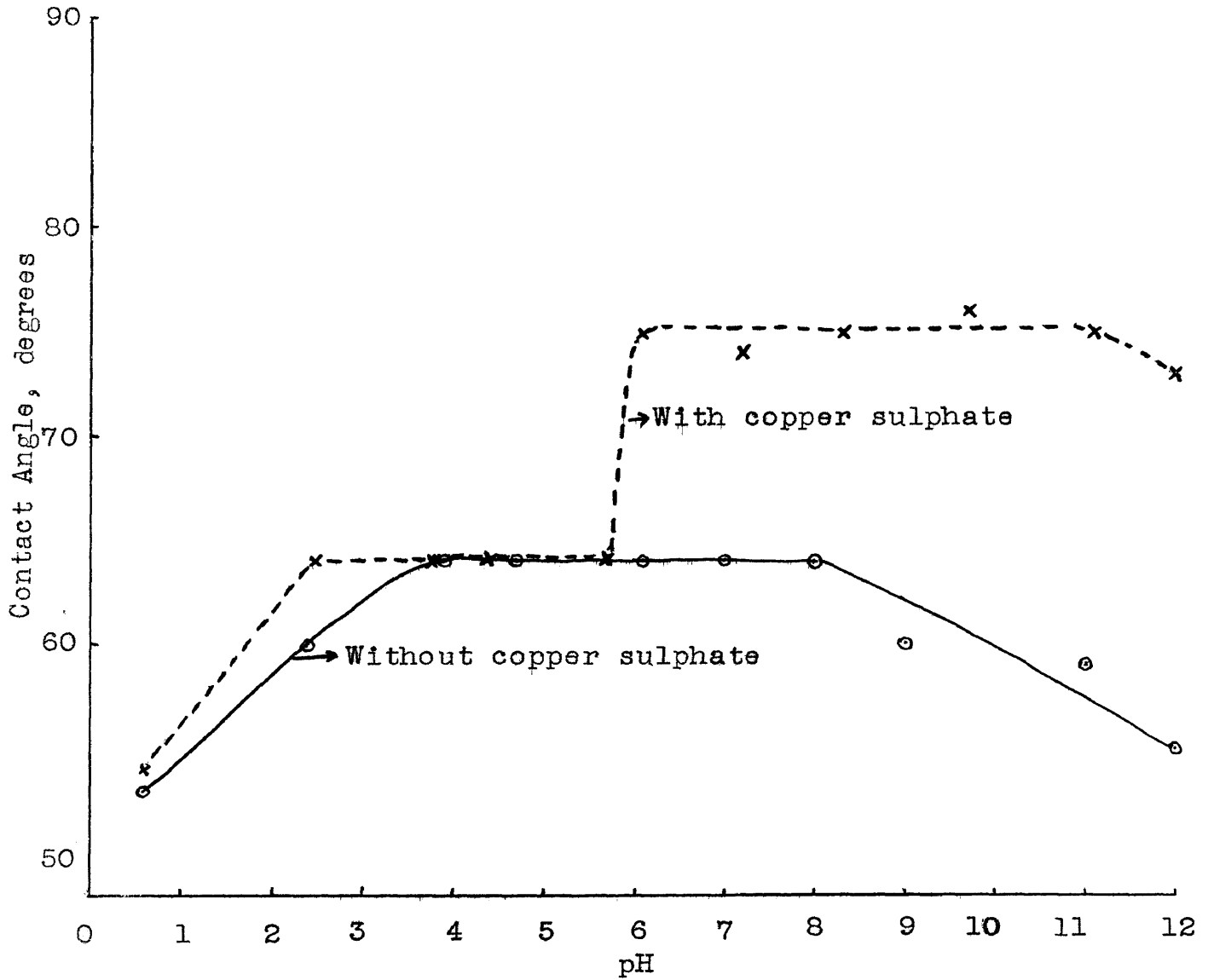
Contact Angles of Sphalerite in Tallow Amine (14.5 mg per liter) and Frother 70 (14.5 mg per liter) with Copper Sulphate (14.5 mg per liter) at Various pH

pH	Angle (deg)
0.6	54
2.5	64
3.8	64
4.4	64
5.7	64
6.1*	75
7.2	74
8.3	75
9.7	76
11.1	75
12.0	73

(*) Indicates the pH of the original solution before adjustment with HCl or NaOH.

Figure 15

Contact Angles of Sphalerite in Tallow Amine (14.5 mg per liter) and Frother 70 (14.5 mg per liter) at Various pH (Tables 15 and 16)



DISCUSSION OF RESULTS

The result from the flotation tests agrees with the one obtained from the contact-angle tests. A high recovery of the mineral coincides with a large contact angle, and a low recovery with a small angle. Figs. 16, 17, and 18 show a combined plot of the data of both tests.

Non-flotation of sphalerite with potassium ethyl xanthate can be seen in the data both in the neutral and alkaline side. However, partial flotation occurs in the acid side.

Both Coco Amine and Tallow Amine can be used for floating sphalerite and a slight increase in recovery is shown on the alkaline side of neutrality.

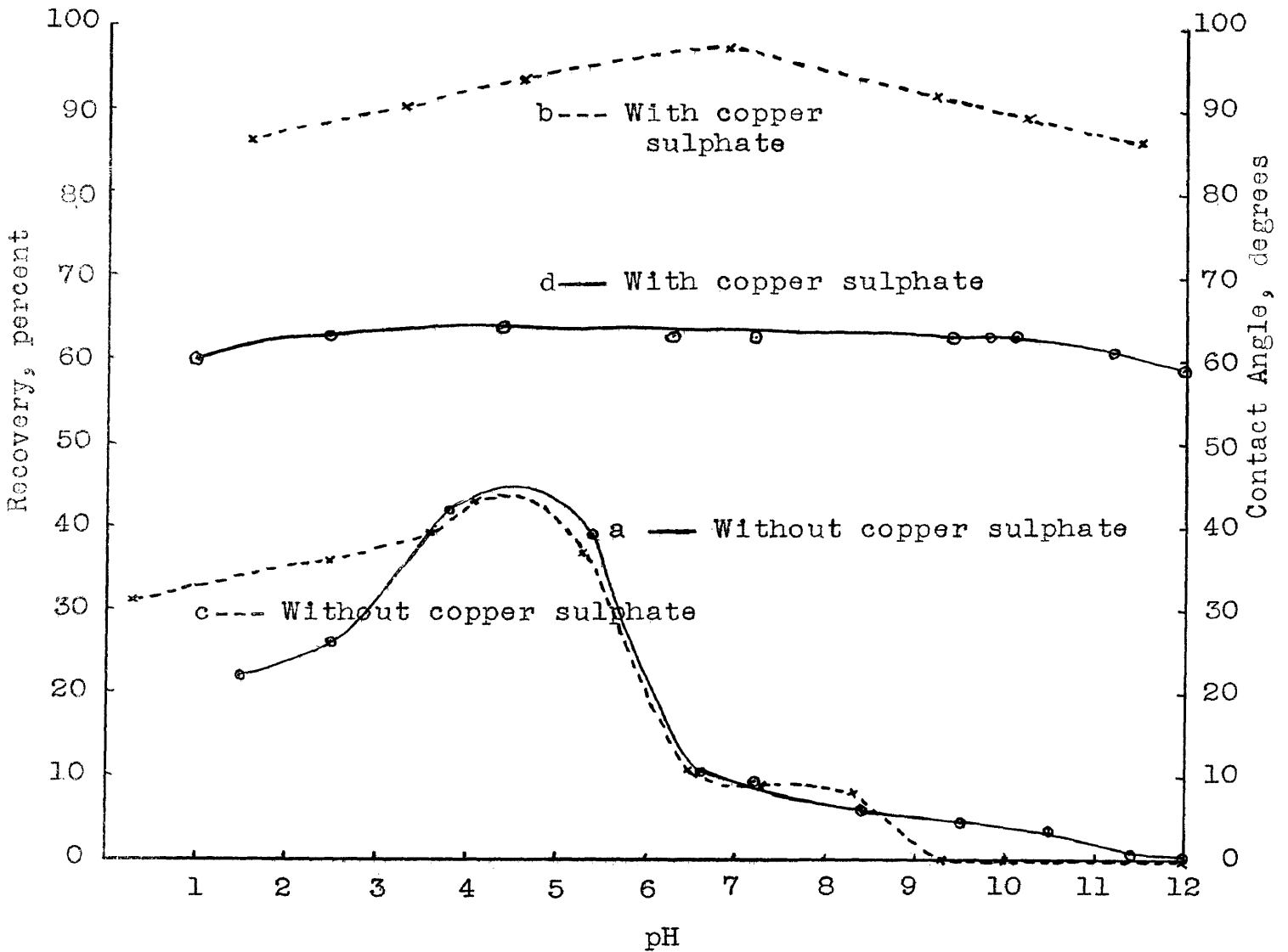
The addition of copper sulphate increases both recovery and contact angle in all cases.

At very high alkalinity and acidity a drop in recovery and a decrease in contact angle occur. This lack of recovery agrees with the one described by Gaudin (1957,

p. 283). The phenomena can be interpreted as a result of the action of the excess hydrogen and hydroxyl ions in competition with the anions and cations of the collector for the mineral surface.

Figure 16

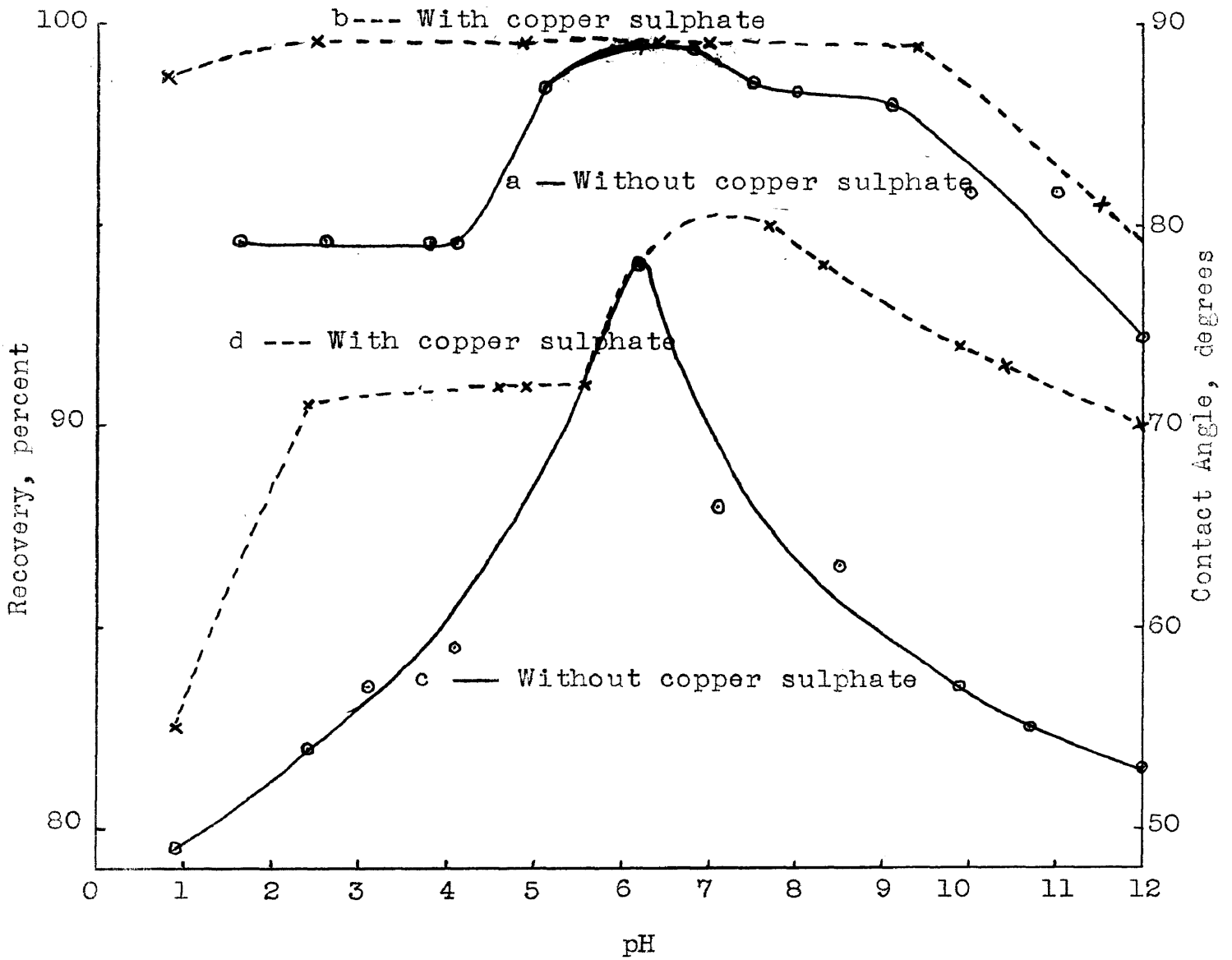
Recovery and Contact Angles of Sphalerite with Potassium Ethyl Xanthate and Frother 70 at Various pH (Tables 5, 6, 11, and 12)



- (a) Flotation curve of sphalerite without copper sulphate.
- - - (b) Flotation curve of sphalerite with copper sulphate.
- - - (c) Contact-angle curve of sphalerite without copper sulphate.
- (d) Contact-angle curve of sphalerite with copper sulphate.

Figure 17

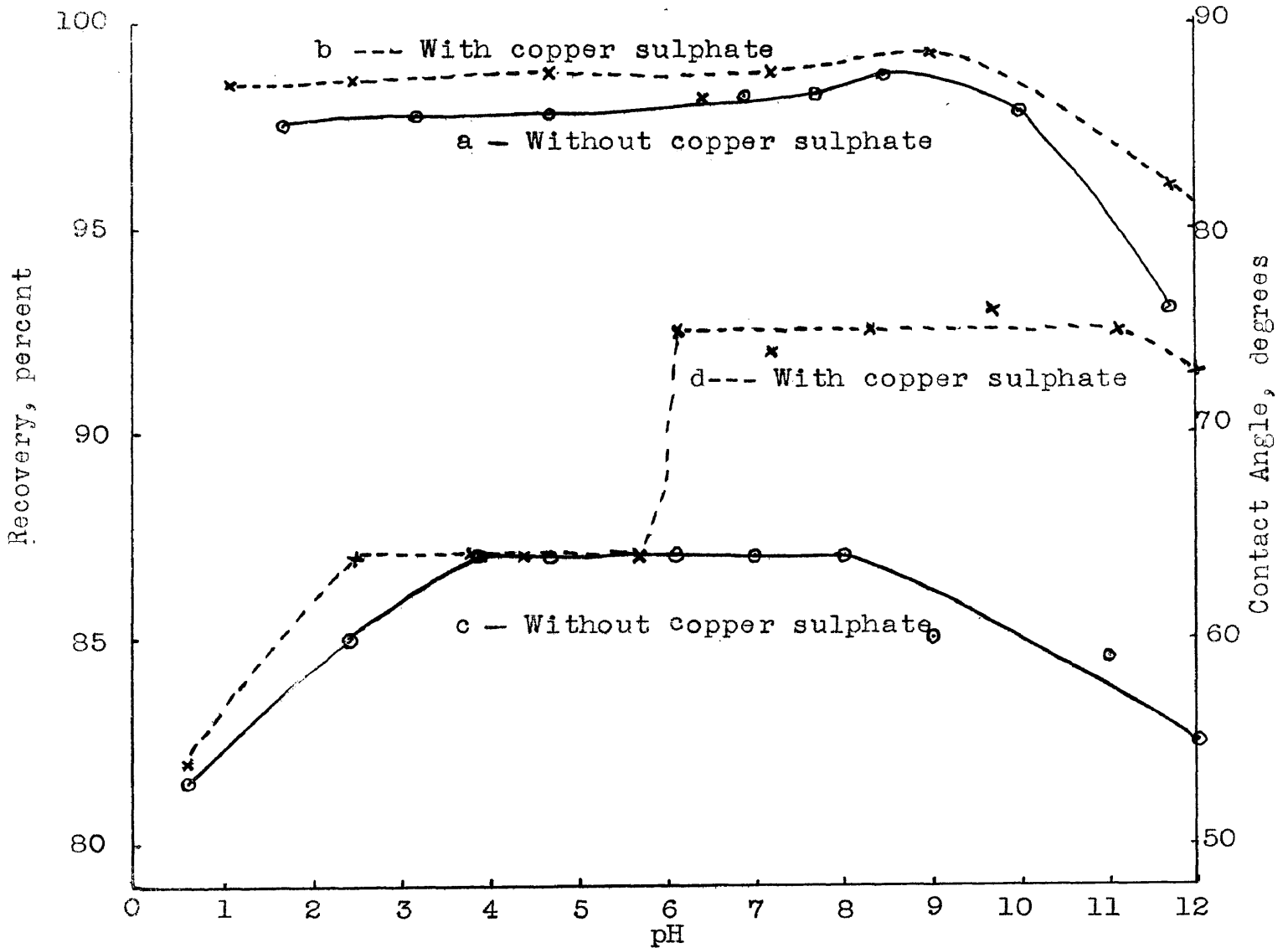
Recovery and Contact Angles of Sphalerite with Coco Amine and Frother 70 at Various pH (Tables 7, 8, 13, and 14)



- (a) Flotation curve of sphalerite without copper sulphate.
- (b) Flotation curve of sphalerite with copper sulphate.
- (c) Contact-angle curve of sphalerite without copper sulphate.
- (d) Contact-angle curve of sphalerite with copper sulphate.

Figure 18

Recovery and Contact Angles of Sphalerite with Tallow Amine and Frother 70 at Various pH (Tables 9, 10, 15, and 16)



- (a) Flotation curve of sphalerite without copper sulphate.
- (b) Flotation curve of sphalerite with copper sulphate.
- (c) Contact-angle curve of sphalerite without copper sulphate.
- (d) Contact-angle curve of sphalerite with copper sulphate.

EXPERIMENTAL LIMITATIONS

A 100 percent recovery could not be obtained because of the impurities in the ore. A sample floated only with Frother 70 (American Cyanamid Company) showed a little bit of floating, probably because of oil contamination from the handling of the mineral or from the collecting effect of the frother.

Flotation of the sample in the alkaline as well as in the acid side gave a loss of approximately 0.4 g as a result of the dissolving action of sphalerite in the base or acid.

The tendency of sticking of mineral-laden bubbles to the cell wall during amine flotation resulted in a slightly lighter weight of the concentrate.

The copper content raised the recovery a little and thus caused an inaccurate picture of the floatability of pure sphalerite.

Contact-angle measurement below 10 deg is difficult. Data recording of angles below 10 deg was taken from an average of 5 readings at different places on the mineral surface.

Contact-angles could be read accurately to 1 deg.

The pH-meter recorded pH values accurately to 0.1.

The analytical balance could weigh to 0.01 mg with accuracy.

The percent error of the chemical analysis was 0.01 percent.

Percent recovery could be calculated to 0.1 percent with accuracy.

CONCLUSIONS

The conclusions derived from this investigation are listed below.

1. Pure sphalerite is not appreciably floated by potassium ethyl xanthate, except on the acid side where about 40 percent recovery is possible.
2. When pre-treated with copper sulphate the mineral can be floated easily.
3. Very good recovery of sphalerite by flotation occurs when intermediate and long-chain-amine salts are used.
4. In both cases pre-treatment with copper sulphate aids in the recovery of the mineral.
5. Activation and depression were also studied by the contact-angle method. It was found that there is a minimum angle above which a mineral is floatable. Any increase in angle above this minimum does not necessarily result in an increase of

recovery when the flotation method is used.

6. The contact angle is only a proportionality factor relating to the floatability of a mineral. Flotation tests must still be performed in order to determine the possible percents of recovery.
7. The fine material in a flotation test has a much larger surface area than the individual mineral in the contact-angle test. Consequently it would be necessary to use collector solution of different concentrations to achieve an equal result. It would be necessary to perform preliminary tests in order to determine the amounts of reagent necessary for determining the range of concentration which would include maximum recovery.

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