

SOME ASPECTS OF THE
EFFECT OF TEMPERATURE 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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Date *January 27th*, 1954

ACKNOWLEDGMENT

The writer wishes to express his gratefulness to Professor Arthur P. Wichmann for having granted the invaluable help of his knowledge and experience during the progress of this research.

The writer feels indebted to Mr. A.L.Pierce, Chemist, Colorado School of Mines Experimental Plant, for the analytical work connected with this investigation, which he performed with outstanding ability and invaluable rapidity.

And finally, the writer wishes to acknowledge with thanks the suggestions of Mr. Carl Martin, of the Colorado School of Mines Experimental Plant.

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INTRODUCTION

The growing need for high-grade concentrates requires the intensive exploitation of all the ore bodies from which such concentrates can be obtained. The exhaustion of the old, rich ore bodies has focused the attention of the mining companies on the low-grade ores, which are more common and contain remarkable amounts of the elements so essential to modern industry.

For almost half a century the flotation processes have proved their efficiency in the concentration of many metallic and nonmetallic minerals. Like many other processes of revolutionary importance in the technical development of the modern industry, the flotation techniques are not the creation of armchair engineers or research physicists. Just as for many other old techniques, rational research to explain the mechanism of the phenomena resulting in the processes of flotation has only recently been undertaken. Though the results of this research are at present far from able to give a satisfactory explanation of the phenomena involved, at least they have shown that the mechanism of collection depends upon several physical variables.

Temperature seems to be one of the least understood of

these variables.

Very likely the influence of temperature on flotation was first observed by an observant flotation operator rather than by a researcher or a physicist. The varying efficiency of plants treating the same minerals but located in regions showing strong differences in their climates, must have certainly puzzled the more alert mineral-dressing engineers. The peculiar changes in the efficiency of the same plant with the change in season probably have produced more than one problem for the manager.

The foregoing circumstances are probably the cause of the heat-treatment techniques already adopted by certain plants on a rather empirical basis.

The development of the modern theories of solids, the refinement of the understanding of the surface phenomena, and the use of modern techniques will be useful tools by means of which the researchers will be able to comprehend and to formulate a theory capable of explaining these phenomena.

The aim of the author was not a research involving all the most important minerals and all the known reagents, for such a problem would have spread over an unreasonably large area. Nor was the objective to include all of the fundamentals involved, which obviously would require the textbook-sized development of an acceptable theory of flotation, which at this date does not yet exist.

The experiments were limited to six ores -- a fluorspar ore, a manganese oxide ore, two zinc ores, and two lead ores -- and

to a limited number of reagents chosen among those most currently used in flotation practice.

The experiments were carried out at different temperatures, with all the other flotation variables held constant, as shown on the following pages.

The first part of this paper is devoted to the review of the leading hypotheses of collection which are most generally accepted at present and to the development of a basic hypothesis concerning the effect of temperature on collection.

The second part of the paper is a detailed report on the tests performed and on the observations regarding them.

The third part of the paper presents the conclusions drawn from the analysis of the experimental results.

The paper is presented under the following main headings:

Collecting Power and Temperature

Experimental Work

Conclusions

COLLECTING POWER AND TEMPERATURE

Three Main Hypotheses on Collector-Coating Mechanism

Ever since flotation has become one of the most important mineral beneficiation processes, a number of theories have been proposed to explain what happens from the moment in which the mineral enters in contact with the different reagents to the time at which the concentrate-bearing froth is removed from the last flotation cell.

The leading hypotheses which are most generally accepted at present are the chemical-reaction hypothesis, the "ionic" adsorption hypothesis, and the "neutral molecule" adsorption hypothesis.

The chemical-reaction hypothesis is stated as follows by Taggart, Taylor, and Knoll ^{1/}: " All dissolved reagents which, in flotation pulps either by action on the to-be-floated or on the not-to-be-floated particles affect their floatability, function by reason of chemical reactions of well recognized types between the reagents and the particle affected."

The "ionic" adsorption hypothesis proposed by Wark ^{2/} and supported by Gaudin ^{3/} has been stated by the latter as follows: " All ions dissolved in a flotation pulp liquor

adsorb at mineral surfaces. At each mineral surface, the adsorption of each dissolved ion is specific; i.e. it depends upon the dissolved ion and upon the mineral; this specific ion adsorption is also a function of the concentration of the dissolved ion under consideration and of that of other dissolved ions. If and when a sufficient proportion of the mineral surface is covered by the effective collector ions, the particle becomes floatable."

The theory of "neutral molecule" adsorption advanced by Cook ^{4/} asserts that "only the adsorption of neutral collector molecules will render a surface hydrophobic and capable of adhering to an air bubble. The adsorption of ions in pairs to occupy adjacent surface sites is regarded, if it should occur, to be equivalent to molecular adsorption. In general the free acid, (HX), formed by hydrolysis of the collector salt, will be the effective anionic collecting agent, and the free base, (ROH), similarly formed, will be the effective cationic collector."

The chemical reaction theory is at present the object of strong criticism, particularly by Wark and Cox ^{5/}. Their main objection is that some of the salts which, according to Taggart, the collector forms with the elements of the mineral are not formed when the same collector is made to react with the same elements not assembled in the crystalline structure.

The adsorption theory seems to be closer to the physical reality; furthermore a rather satisfactory explanation of the effects of temperature on flotation can be obtained by

adopting it.

Adsorption and Temperature

According to the modern physico-chemical viewpoint ^{6/}
" the surface of a liquid is in a state of strain or unsaturation, and that of a solid has, similarly, a residual field of force; there will consequently be a tendency which is ultimately responsible for the phenomenon of adsorption" and
" it is very probable that adsorption occurs on all surfaces."

Experimental works have shown that variations of pressure and temperature produce remarkable variations of the extent of adsorption and that adsorption is related to the characteristics both of the adsorbent and of the adsorbate.

It has been accepted for some years that there are two main types of adsorption of gases by solids ^{7/}. The first, known as Van der Waals adsorption, involves forces of a physical nature, such as the "dispersion forces" discussed by F. London; the second type involves attractions analogous to valence.

Van der Waals adsorption is characterized by relatively small heats of adsorption and by the fact that the equilibrium between solid and gas is reversible.

The second type of adsorption, called chemisorption because it involves forces of a chemical nature, occurs especially at higher temperatures. The fact that the forces are similar to those concerned in chemical combination is indicated by the heats of adsorption, which are of the order of

20 to 100 kilocalories per mole $\frac{6}{}$.

The bonds formed between the material of the surface and the adsorbed gas are thus almost as strong as those existing in stable stoichiometric compounds. Some evidence for the view according to which chemisorption, also called "activated adsorption", involves forces of a chemical nature is provided by the fact that the adsorption is often irreversible.

The adsorption processes for gases on solids have been studied mathematically by means of the theory of absolute reaction rates $\frac{7}{}$, under the assumption that the adsorption process is simply a bimolecular reaction involving a molecule or atom from the gas phase and an atom of the solid or, in general, an active point occupying a fixed position on the adsorbing surface.

Reaction, i.e., adsorption, then involves the formation of an activated complex between the gas molecule and the point on the surface, and the rate of the process is given by the rate of passage of this complex over a potential-energy barrier. The height of the barrier is, of course, the energy of activation for adsorption.

The basic formula for the reaction rate is

$$V = c_g c_s \frac{kT}{h} \frac{f^{\ddagger}}{f_g f_s} e^{-\frac{E}{kT}}, \quad (1)$$

where:

c_g is the concentration in gas phase;

c_s is the concentration of adsorption centers;

- f^* is the complete partition function for the activated complexes;
- F_g represents the complete partition function for unit volume of the gas undergoing adsorption;
- f_s is the complete partition function for the adsorption centers;
- k is the Boltzmann's constant;
- h is the Planck's constant;
- E represents the energy of activation for adsorption per single molecule at the absolute zero;
- T represents the absolute temperature of the system.

Further assumptions on the kinetic state of the adsorbed layers allow a more specific statement of the partition function involved. The preceding analytical expression of the rate of adsorption is based upon the fact that the adsorbate particles are in the gaseous state before adsorption and furthermore that the surface of the solid is perfectly uniform.

In the specific case of the problem we are referring to, the molecules are in liquid phase and the solid surfaces are far from being uniform. Very likely, therefore, the effects due to the irregularity of the surface and those accompanying the existence of a liquid phase make it impossible to use Equation 1 for quantitative work; nevertheless the importance of Equation 1 depends upon the fact that it shows the importance of temperature on the acceleration of the adsorption

processes when the energy of activation E is not negligible; and there is no reason to prevent us from assuming that an equation of the type

$$V = f(a, b, c, \dots, T) \quad (2)$$

holds for adsorption from liquids.

Unfortunately, an equation of type 2 has not yet been discovered, as far as I know.

Cook and Last in one of their papers ^{4/} have used an equation substantially equal to Equation 1 as one of the starting points for their theory of the collection mechanism of oleic acid on fluorspar.

The experiments carried out during the present research and described later, were undertaken to show the effect of temperature upon the collecting power of a certain number of reagents in respect to a certain number of minerals.

The basic assumption has been, in line with the theory of Last and Cook, that whenever it is reasonable to believe that the collector-coating occurs as an adsorption phenomenon, then the effect of temperature must be remarkable, in agreement with the dimensional Equation 2.

Relationship Between Collecting Power of Various Reagents and Temperature

1) Fatty Acids

In a paper of fundamental importance in regard to the explanation of the phenomena involved in flotation processes,

which appeared in 1927, A.F.Gaudin ^{3/} described the results obtained by a series of tests carried out on galena with lauric acid, with a constant amount of reagent and at different temperatures. The tests showed conclusively that this acid is a satisfactory reagent when used at temperatures above its melting point, and that its efficiency increases with temperature.

Unfortunately the paper does not specify whether the ore was a synthetic one or, if not, what kind of gangue was associated with galena. No explanation was given by the author, but the example was given to demonstrate the fallacy of the view of other authors according to whom the success of the fatty acids as collectors should depend upon the presence or absence of the double bond in the molecules of the fatty acids.

In a paper which appeared 26 years later, in 1953, R.T. Hukki and O.Vartianen ^{2/} of the Institute of Technology of Finland reported the result of a preliminary investigation of the collecting effects of various fatty acids as follows: " The collecting power of fatty acids used in flotation increases with increasing unsaturation of the hydrocarbon chain."

The two statements, one by Gaudin and the other by the Finnish researchers, are apparently not in contradiction, but an interesting question is whether the increase of collecting power produced by temperature is or is not related to the unsaturation of the hydrocarbon chain.

A clarification of this point might obviously throw new light also on the basic problems concerning the collection me-

chanism.

The first thorough research on the effect of temperature on fatty-acid flotation was successfully carried out by Cook, Last, and collaborators, and the results were reported in the previously cited paper 4/.

In this paper it was shown that by the application of two new techniques both involving heat treatment of the conditioned pulp, far better results than those obtained by the conventional technique were brought about.

Some fluorspar flotation plants are at present pre-heating the collector-conditioned pulp by injection of steam into tanks.

2) Xanthates

The effect of temperature on flotation is reported in a general manner in the textbook of I.W.Wark 2/. Most of the research work pertaining to the effect of temperature on xanthate collection was performed by Wark and Cox.

Their research was mostly concerned with fundamentals, but its conclusions are also of great interest for practical application.

According to the above-mentioned authors 10/ "over a comparatively limited range it has been found that temperature has no effect on the value of the contact angle at a galena surface".

The authors explain this result by the fact that the contact angles depend upon the temperature coefficients of surface tension, which are usually small 11/.

It is interesting to observe that for a long time the collector coating of galena with xanthate has been recognized as a chemical reaction and actually has constituted one of the strongholds for Taggart's chemical theory of flotation 12/.

The fact that an adsorption theory has been proposed in order to explain the phenomena involved in the collector coating mechanism does not necessarily imply that the collection is always basically an adsorption phenomenon; an outstanding exception might be this one of galena.

At the time of the present research it has not yet been established whether or not temperature has any effect on galena flotation with xanthates.

In a subsequent paper 13/ a study was made by Wark and Cox of the influence of temperature on adsorption of xanthate at surfaces of galena, sphalerite, pyrite, arsenopyrite, and chalcopyrite, and on the effects of alkali, cyanide, and copper sulphate in hindering or promoting adsorption. The development of a definite air-water-mineral contact angle was used to indicate the adsorption of a xanthate film on the mineral surface.

Among other results it was found that (1) the conditions most favorable for floating sphalerite away from pyrite are low temperature, low xanthate concentration, and if low temperature is impracticable, a narrow range of pH values, which for the conditions used was between 6 and 8; (2) the differentiation between the behavior of sphalerite and pyrite

when using amyl xanthate in a circuit containing copper sulphate and cyanide is much diminished as the temperature is raised.

The influence of alkalis, cyanide, and copper sulphate on the adsorption of the collector mercaptobenzthiazole (Flotagen) by the minerals galena, sphalerite, pyrite, and chalcoppyrite was investigated by Wark and Cox for the two temperatures 10° C and 35° C. 14/. The captive-bubble method was used to test for adsorption.

Among other results it was found that (1) in the absence of copper sulphate the minerals respond to this collector in the same order that they respond to ethyl xanthate; (2) in the presence of copper sulphate there is excellent differentiation between the behavior of pyrite and sphalerite, and the results obtained are typical of the xanthate type, provided they are used in suitable concentration and at the correct temperature.

Flotation Practice Utilizing Temperature Control

Very little has been written about the control of temperature in actual flotation practice.

A paper by D.R.Mitchell, H.E.Gross, and H.E.Oehler 15/ reports that flotation was carried out in a plant at Trail, British Columbia, with oleic acid and soda ash at 30° C. in Gallow cells for the flotation of fluorspar ore.

Heat treatment of the collector-treated fluorspar pulp precedes flotation at the concentrator of Reynolds Mining

Company at Salida, Colorado.

Taggart 16/ refers to some plants in which heat treatment is applied.

Temperature control is used in the flotation of sphalerite at the Resurrection Mining Company concentrator in Leadville, Colorado.

An article concerning the marmatite flotation at the New Jersey Zinc Company concentrator at Gilman, Colorado, also states that both the galena and the marmatite conditioned pulps are subjected to temperature control 17/.

EXPERIMENTAL WORK

Introduction

The research deals with five minerals: fluorspar, manganese oxide, sphalerite, marmatite, and galena.

Fatty acids and xanthates were generally the collectors used; the collectors are specifically cited in the description of the individual experiments. The fluorspar tests are designated F-1, F-2, etc; the manganese oxide tests M-1, M-2, etc; the zinc ores tests Z-1, Z-2, etc; and the galena tests G-1, G-2, etc.

For every combination of mineral and collector one or more tests were carried out without heat treatment at about the temperature of Golden tap water; the actual temperature is reported in all cases.

The ground and conditioned pulp was transferred to a container, which was either a four-liter pyrex beaker or an eight-liter enameled bucket. The container was then placed on a hot plate (Photograph 1), and continuously stirred during heating. A thermometer was continuously immersed in the pulp.

This system has two disadvantages. First it is impossible to ascertain the influence of the time (usually about 30 minutes) necessary to bring the pulp from the temperature of the tap water to the desired higher value. Regardless of whether the collector-coating mechanism is a chemical reaction or is activated adsorption, the time of exposure of the pulp to heat has an influence on the rate of the process involved.

Second, when the temperature of the pulp nears the boiling point of water, the amount of vapor produced is usually so large that an increase of a few degrees requires a very long time.

Grinding

Batch grinding of the feed for flotation tests was generally performed in laboratory ball mills. Usually the conical ball mill shown in photograph 2 was used; for a few tests a cylindrical ball mill having the following characteristics was preferred (Photograph 3) :

Dimensions: 7 x $7\frac{1}{2}$ in.

Charge: 9.7 kg of cast steel balls

Speed: 90 rpm

For wet grinding, Golden tap water having a pH range between 7 and 7.5 was used; the dilution was always 1 to 1.

pH Measurement

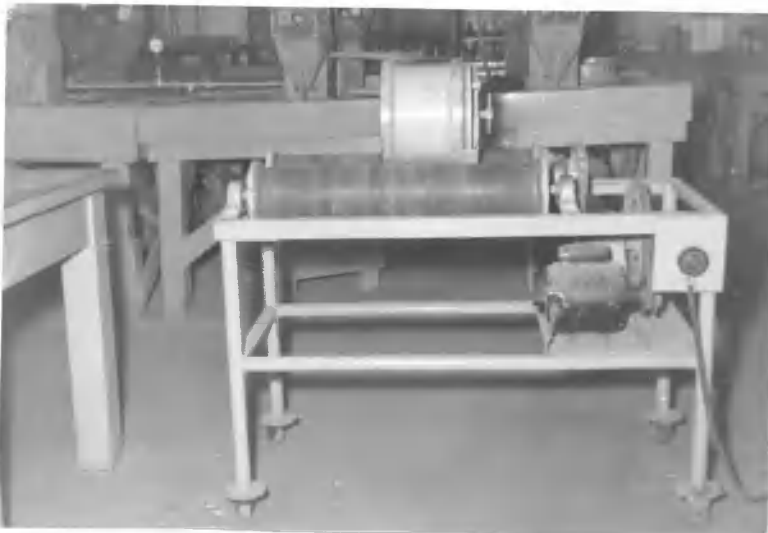
The pH of the pulp was always measured by electrometric method. A portable Beckmann pH-meter was used, and the samples



Photograph 1



Photograph 2



Photograph 3



Photograph 4



Photograph 5

were always at room temperature.

Flotation Machines and Procedure

Two Fagergren subaeration 600-gram laboratory flotation machines equipped with stainless-steel bowls with sloping sides (Photograph 4), which may be substituted by glass bowls, were used. The froth was raked off by means of suitable spatulas and allowed to fall into enameled pans (Photograph 5).

Fluorspar Flotation Tests

A large amount of flotation work has already been done on fluorspar. The study of the effect of temperature on flotation of fluorspar was purposely chosen to constitute the first series of tests. The knowledge already acquired on this subject by other researchers served as a guide for the experiments reported herein.

The ore used was a fluorspar ore from Jamestown, Colorado, of the following composition:

CaF ₂	64.70 %
CaO	5.48 %
Insoluble plus sulphides	29.52 %

Twelve tests were made. Three were carried out without heating the pulp; four were performed by heating the wet conditioned pulp; three were performed by conditioning the dry ore with wet reagents, grinding this mixture at this high percentage of solids and heat treating; two were carried out

by mixing dry powdered reagents with the dry ore, dry grinding, and heat treating.

Since the Fluorapatite in this ore was liberated at 100 mesh, the ore for all experiments was ground to this fineness.

Test F-1

Grind: 1000 gm of ore
 for 8 min in ball mill with
 1000 ml of tap water
 2.5 lb per ton of sodium oleate
 5.0 lb per ton of Na_2CO_3
 1.0 lb per ton of Quebracho

Temperature of pulp: 70° F.

Desliming: none

Heat treatment: none

Flotation: conditioning time, 5 min
 stages, 1 rougher and 5 cleaners

Stage	Addition (lb per ton)	Froth Removal Time (min)
Rougher	1.5 sodium oleate 5.0 Na_2CO_3 1.6 Quebracho	25
1st cleaner	As in rougher	6
2nd cleaner	As in rougher	5
3rd cleaner	0.05 Quebracho	
4th cleaner	None	
5th cleaner	None	

Test F-1 (cont'd)

Results:

Product	Weight (gm)	CaF ₂ Assay (%)
Concentrate	440	92.8
Final tailing	105	59.1
1st cleaner tailing	160	52.1
2nd cleaner tailing	140	7.5
3rd cleaner tailing	30	8.1
4th cleaner tailing	10	27.9
5th cleaner tailing	40	67.9

Ratio of concentration: 1 to 2.27

Percentage of recovery: 63.1 %

Test F-2

Grind: 1000 gm of ore
 for 15 min in ball mill with
 1000 ml of tap water
 1.5 lb per ton of oleic acid
 5.0 lb per ton of Na_2CO_3
 1.0 lb per ton of Quebracho

Temperature of pulp: 68° F.

Desliming: none

Heat treatment: none

Flotation: conditioning time, 5 min
 stages, 1 rougher and 5 cleaners

Stage	Addition (lb per ton)	Froth Removal Time (min)
Rougher	---	10
1st cleaner	---	8
2nd cleaner	---	10
3rd cleaner	---	8
4th cleaner	0.05 Quebracho	10
5th cleaner	0.05 Quebracho	15

Test F-2 (cont'd)

Results:

Product	Weight (gm)	CaF ₂ Assay (%)
Concentrate	471	85.3
Final tailing	208	28.7
1st cleaner tailing	65	46.5
2nd cleaner tailing	24	37.6
3rd cleaner tailing	7	41.0
4th cleaner tailing	3	47.7
5th cleaner tailing	10	62.7

Ratio of concentration: 1 to 2.12

Percentage of recovery: 62.15 %

Test F-3

Grind: 1000 gm of ore
 for 6 min in ball mill with
 1000 ml of tap water
 1.5 lb per ton of sodium oleate
 5.0 lb per ton of Na_2CO_3
 1.0 lb per ton of Quebracho

Temperature of pulp: 67° F.

Desliming: yes

Heat treatment: none

Flotation: conditioning time, 7 min
 stages, 1 rougher and 5 cleaners

Stage	Addition (lb per ton)	Froth Removal Time (min)
Rougher	0.3 Quebracho 1.0 sodium oleate	20
1st cleaner	---	15
2nd cleaner	0.1 Quebracho	17
3rd cleaner	1.5 sodium oleate 0.1 Quebracho	25
4th cleaner	0.1 Quebracho	20
5th cleaner	0.1 Quebracho 1.5 sodium oleate	15

Test F-3 (cont'd)

Results:

Product	Weight (gm)	CaF ₂ Assay (%)
Concentrate	270	95.6
Slimes	90	54.1
Final tailing	428	52.4
1st cleaner tailing	90	41.3
2nd cleaner tailing	35	49.1
3rd cleaner tailing	10	38.2
4th cleaner tailing	25	54.6
5th cleaner tailing	5	44.0

Ratio of concentration: 1 to 3.7

Percentage of recovery: 40 %

Test F-4

Grind: 1000 gm of ore
 for 8 min in ball mill with
 1000 ml of tap water
 2.0 lb per ton of oleic acid
 5.0 lb per ton of Na_2CO_3
 1.5 lb per ton of Quebracho

Temperature of pulp: 82° F.

Desliming: none

Heat treatment: 25 min of heating on hot plate,
 5 min of boiling at 202° F.

Flotation: conditioning time, 4 min
 stages, 1 rougher and 5 cleaners

Stage	Addition (lb per ton)	Froth Removal Time (min)
Rougher	---	9
1st cleaner	---	2
2nd cleaner	---	2
3rd cleaner	---	2
4th cleaner	---	2
5th cleaner	---	2

Test P-4 (cont'd)

Results:

Product	Weight (gm)	CaF ₂ Assay (%)
Concentrate	600	95.6
Final tailing	250	6.5
1st cleaner tailing	50	16.7
2nd cleaner tailing	12	20.9
3rd cleaner tailing	5	27.5
4th cleaner tailing	4	36.1
5th cleaner tailing	4	52.7

Ratio of concentration: 1 to 1.66

Percentage of recovery: 38.6 %

Test F-5

Grind: as in Test F-4

Temperature of pulp: 80° F.

Desliming: none

Heat treatment: 20 min of heating on hot plate,
15 min of boiling at 202° F.

Flotation: as in Test F-4

Results:

Product	Weight (gm)	CaF ₂ Assay (%)
Concentrate	584	95.6
Final tailing	283	10.3
1st cleaner tailing	49	15.6
2nd cleaner tailing	14	20.0
3rd cleaner tailing	10	25.7
4th cleaner tailing	8	21.2
5th cleaner tailing	5	42.1

Ratio of concentration: 1 to 1.71

Percentage of recovery: 86.3 %

Test F-6

Grind: 1200 gm of ore
 for 10 min in ball mill with
 1000 ml of tap water
 2.5 lb per ton of oleic acid
 10.0 lb per ton of Na_2CO_3
 1.5 lb per ton of Quebracho

Temperature of pulp: 80° F.

Desliming: none

Heat treatment: heating to 167° F.

Flotation: conditioning time, 5 min
 stages, 1 rougher and 4 cleaners

Results:

Product	Weight (gm)	CaF_2 Assay (%)
Concentrate	674	96.1
Final tailing	295	7.3
1st cleaner tailing	95	21.8
2nd cleaner tailing	72	49.3
3rd cleaner tailing	29	52.4
4th cleaner tailing	17	66.6

Ratio of concentration: 1 to 1.78

Percentage of recovery: 83.4 %

Test F-7

Grind: 1000 gm of ore
 for 10 min in ball mill with
 1000 ml of tap water
 2.5 lb per ton of oleic acid
 10.0 lb per ton of Na_2CO_3
 1.5 lb per ton of Quebracho

Desliming: none

Heat treatment: heating to 140° F.

Flotation: conditioning time, 5 min
 stages, 1 rougher and 4 cleaners

Results:

Product	Weight (gm)	CaF_2 Assay (%)
Concentrate	519	96.4
Final tailing	292	5.6
1st cleaner tailing	97	26.5
2nd cleaner tailing	57	52.4
3rd cleaner tailing	15	52.7
4th cleaner tailing	20	78.6

Ratio of concentration: 1 to 1.93

Percentage of recovery: 77.1 %

Test 2-8

Grind: 1000 gm of ore
for 10 min in 7 x 7½-in. rod mill with
2.5 lb per ton of oleic acid
10.0 lb per ton of Na₂CO₃
1.5 lb per ton of Quebracho

Heat treatment: 1 hour at 100° C.

Flotation: addition of water to the heat-treated
ore and, after 5 min of agitation, re-
moval of the froth

Results: no quantitative results

Test F-9

Grind: as in Test F-8

Heat treatment: 1 hour at 125° C.

Flotation: as in Test F-8

Results: no quantitative results

Test F-10

Grind: 1000 gm of ore
 for 15 min in 7 x 7½-in. ball mill with
 2.5 lb per ton of oleic acid
 10.0 lb per ton of Na₂CO₃
 1.5 lb per ton of Quebracho

Heat treatment: 1 hour at 110° C.

Flotation: addition of water to the heat-treated
 ore and, after 5 min agitation, 1
 rougher and 4 cleaner stages

Results:

Product	Weight (gm)	CaF ₂ Assay (%)
Concentrate	406	92.2
Final tailing	468	45.5
1st cleaner tailing	35	40.4
2nd cleaner tailing	15	46.3
3rd cleaner tailing	12	63.3
4th cleaner tailing	10	64.4

Ratio of concentration: 1 to 2.46

Percentage of recovery: 55.6 %

Test F-11

Grind: 1000 gm of ore
 for 20 min in 7 x 7½-in. ball mill with
 the following dry reagents:
 2.5 lb per ton of sodium oleate
 10.0 lb per ton of Na₂CO₃
 1.5 lb per ton of Quebracho

Heat treatment: 6 hours at 110° C.

Flotation: addition of water to the ore immediately after heat treatment; 1 rougher and 4 cleaner stages

Results:

Product	Weight (gm)	CaF ₂ Assay (%)
Concentrates	477	98.1
Final tailing	267	11.2
1st cleaner tailing	78	43.8
2nd cleaner tailing	81	71.6
3rd cleaner tailing	51	89.3
4th cleaner tailing	4	76.3

Ratio of concentration: 1 to 2.1

Percentage of recovery: 72.4 %

Test F-12

Grind: as in Test F-11

Heat treatment: as in Test F-11

Flotation: addition of water to the ore after cooling; 1 rougher and 4 cleaner stages

Results:

Product	Weight (gm)	CaF ₂ Assay (%)
Concentrate	285	96.7
Final tailing	288	20.6
1st cleaner tailing	182	49.3
2nd cleaner tailing	92	65.2
3rd cleaner tailing	65	72.5
4th cleaner tailing	53	76.1

Ratio of concentration: 1 to 3.5

Percentage of recovery: 42.6 %

Manganese Oxide Flotation Tests

The beneficiation of manganese oxide ores is at present one of the most difficult problems in mineral dressing. To date, no efficient process for producing a high-grade manganese oxide concentrate has been devised.

The ore used for the present work was a low-grade, extremely soft manganese oxide ore from Leadville, Colorado, having the following composition:

Fe	10.4	%
Insoluble	15.88	%
Mn	28.00	%
CaO	0.05	%

A 200-pound sample of this ore was comminuted through a jaw crusher and then mixed thoroughly after grinding down to minus 6-mesh in a coffee mill.

Screen analysis of a 300-gram sample of this ore yielded the following results:

Mesh of Screen (Tyler)	Weight Retained (%)	Weight Retained (Cumulative %)
8	0.37	0.37
10	12.32	12.69
20	24.82	37.51
48	25.62	63.13
100	10.82	73.95
200	7.26	81.21
minus 200	13.00	

Test M-1

Grind: 1000 gm of ore
for 10 min in ball mill with
1000 ml of tap water
6.0 lb per ton of oleic acid
2.0 lb per ton of Na_2SiO_3

Temperature of Pulp: 70° F.

pH of pulp: 7.2

Desliming: none

Heat treatment: none

Flotation: 1 stage; froth removal time, 8 min

Results:

Product	Weight (gm)	Mn Assay (%)
Concentrate	440	26.40
Tailing	507	28.30

Test M-2

Grind: 1000 gm of ore
 for 10 min in ball mill with
 1000 ml of tap water
 6.0 lb per ton of low polyunsaturated fatty-acid mixture
 2.0 lb per ton of Na_2SiO_3

Temperature of pulp: 70° F.

pH of pulp: 7.2

Desliming: none

Heat treatment: none

Flotation: 1 stage; froth removal time, 7 min

Results:

Product	Weight (gm)	Mn Assay (%)
Concentrate	455	26.20
Tailing	500	31.7

Test M-3

Grind: 1000 gm of ore
 for 10 min in ball mill with
 1000 ml of water
 6.0 lb per ton of high polyunsaturated fatty-acid mixture
 2.0 lb per ton of Na_2SiO_3

Temperature of pulp: 72° F.

pH of pulp: 7.3

Desliming: none

Heat treatment: none

Flotation: 1 stage; froth removal time, 10 min

Results:

Product	Weight (gm)	Mn Assay (%)
Concentrate	553	32.3
Tailing	385	27.0

Ratio of concentration: 1 to 1.81

Percentage of recovery: 63.8 %

Test M-4

Grind: as in Test M-1

pH of pulp: as in Test M-1

Desliming: none

Heat treatment: heating to 200° F.

Flotation: conditioning time, 4 min
stages, 1 rougher and 2 cleaners

Stage	Addition (lb per ton)	Froth Removal Time (min)
Rougher	---	7
1st cleaner	---	6
2nd cleaner	---	5

Results:

Product	Weight (gm)	Mn Assay (%)
Concentrate	425	29.6
Final tailing	360	32.3
1st cleaner tailing	100	19.1
2nd cleaner tailing	83	22.4

Test M-5

Grind: 1000 gm of ore
 for 10 min in ball mill with
 1000 ml of tap water
 2.0 lb per ton of oleic acid
 4.0 lb per ton of Na_2SiO_3
 8.0 lb per ton of starch

pH of pulp: 7.9

Desliming: none

Heat treatment: heating to 122° F.

Flotation: stages, 1 rougher and 1 cleaner

Stage	Addition (lb per ton)	Froth Removal Time (min)
Rougher	---	8
Cleaner	---	5

Results:

Product	Weight (gm)	Mn Assay (%)
Concentrate	95	26.1
Final tailing	678	26.9
Cleaner tailing	235	25.4

Test M-6

Grind: as in Test M-5

pH of pulp: as in Test M-5

Desliming: none

Heat treatment: heating to 167° F.

Flotation: as in Test M-5

Stage	Addition (lb per ton)	Froth Removal Time (min)
Rougher	---	10
Cleaner	---	5

Result:

Product	Weight (gm)	In Assay (%)
Concentrate	135	27.0
Final tailing	610	27.5
Cleaner tailing	245	25.4

Test M-7

Grind: 1000 gm of ore
 for 10 min in ball mill with
 1000 ml of water
 6.0 lb per ton of high polyunsaturated fatty acid mixture
 4.0 lb per ton of Na_2SiO_3
 8.0 lb per ton of starch

pH of pulp: 7.6

Desliming: none

Heat treatment: heating to 122° F.

Flotation: stages, 1 rougher and 1 cleaner

Stage	Addition (lb per ton)	Froth Removal Time (min)
Rougher	---	8
Cleaner	---	4

Results:

Product	Weight (gm)	Mn Assay (%)
Concentrate	710	28.9
Final tailing	120	22.4
1st cleaner tailing	124	22.5

2 -/ (cont'd)

Ratio of concentration: 1 to 1.41

Percentage of recovery: 70.4 %

Test M-8

Grind: as in Test M-7

Desliming: none

Heat treatment: heating to 167° F.

Flotation: as in Test M-7

Stage	Addition (lb per ton)	Froth Removal Time (min)
Rougher	---	5
Cleaner	---	5

Results:

Product	Weight (gm)	Mn Assay (%)
Concentrate	678	29.2
Final tailing	151	25.5
1st cleaner tailing	165	24.0

Ratio of concentration: 1 to 1.47

Percentage of recovery: 70.6 %

Test M-9

Grind: 1000 gm of ore
for 10 min in ball mill with
1000 ml of tap water
5.0 lb per ton of Na_2SiO_3 .

Desliming: yes

Heat treatment: none

Flotation: 10 min conditioning with
2.0 lb per ton of high polyunsatu-
rated fatty-acid mixture; 1 stage

Results:

Product	Weight (gm)	Mn Assay (%)
Concentrate	140	50.6
Slimes	503	25.0
Tailing	300	31.2

Test M-10

Grind: 1000 gm of ore
 for 40 min in 7 x 7 $\frac{1}{2}$ -in. ball mill
 1000 ml of tap water
 4.0 lb per ton of high polyunsaturated fatty-acid mixture
 4.0 lb per ton of Na₂SiO₃
 4.0 lb per ton of Na₂CO₃
 4.0 lb per ton of neutral hydrocarbon oil

Desliming: none

Heat treatment: none

Flotation: 4 min of agitation after addition of
 8.0 lb per ton of starch; stages, 1
 rougher and 2 cleaners

Stage	Addition (lb per ton)	Froth Removal Time (min)
Rougher	---	5
1st cleaner	---	6
2nd cleaner	$\frac{1}{2}$ of fatty-acid mixture	6

40 (cont'd)

4a:

Product	of 1st (gm)	Recovery (%)
Concentrate	125	31.6
Final tailing	353	25.3
1st cleaner tailing	195	26.6
2nd cleaner tailing	75	24.5

Ratio of concentration: 1 to 3.03

Percentage of recovery: 36.64 %

Test M-11

Grind: as in Test M-10; addition of
3.0 lb per ton of starch

Desliming: none

Heat treatment: heating to 180° F.

Flotation: stages, 1 rougher and 2 cleaners

Stages	Addition (lb per ton)	Froth Removal Time (min)
Rougher	---	8
1st cleaner	---	7
2nd cleaner	---	5

Results:

Product	Weight (gm)	Fe Assay (%)
Concentrate	515	31.3
Final tailing	200	24.2
1st cleaner tailing	105	20.2
2nd cleaner tailing	123	25.2

Ratio of concentration: 1 to 1.94

Percentage of recovery: 57.6 %

Zinc Ore Flotation Tests

For these tests a synthetic sphalerite ore and a marmatite ore were used.

The synthetic ore was made up of 20% of sphalerite jig concentrate, containing 61.2% zinc, and 80% silica. The marmatite ore from Gilman, Colorado, contained about 70% pyrite, 12.5% zinc, and minor amounts of galena, carbonates, and silicates.

Galena flotation always preceded the tests performed on marmatite ore. Therefore, the percentage of recovery was also calculated for the pulp after galena flotation, in order to take into account the losses of marmatite in the galena concentrate.

Test Z-1

Grind: 1000 gm of synthetic ore
for 8 min in ball mill with
1000 ml of tap water
1.0 lb per ton of oleic acid

Temperature of pulp: 72° F.

Heat treatment: none

pH of pulp: 9.0

Flotation: 1 stage

Results:

Product	Weight (gm)	Zn Assay (%)
Concentrate	93	16.8
Tailing	876	12.2

Ratio of concentration: 1 to 11.1

Percentage of recovery: 12.9 %

Test Z-2

Grind: as in Test Z-1

Temperature of pulp: 80° F.

pH of pulp: 8.0 after grinding
4.5 after addition of H₂SO₄

Heat treatment: none

Flotation: 1 stage

Results:

Product	Weight (gm)	Zn Assay (%)
Concentrate	145	19.0
Tailing	845	11.1

Ratio of concentration: 1 to 6.9

Percentage of recovery: 22.43 %

Test Z-3

Grind: as in Test Z-1

Heat treatment: 35 min of heating on hot plate,
5 min at 192° F.

Flotation: stages, 1 rougher and 1 cleaner

Product	Weight (gm)	Zn Assay (%)
Concentrate	60	50.4
Final tailing	770	5.8
Cleaner tailing	115	35.3

Ratio of concentration: 1 to 16.7

Percentage of recovery: 24.64 %

Test Z-4

Grind: as in Test Z-1

pH of pulp: 6.8

Heat treatment: heating to 190° F.

Flotation: 1 stage

Results:

Product	Weight (gm)	Zn Assay (%)
Concentrate	210	37.8
Tailing	748	4.6

Ratio of concentration: 1 to 4.76

Percentage of recovery: 65 %

Test Z-5

Grind: 1000 gm of synthetic ore
 for 8 min in ball mill with
 1000 ml of tap water
 1.0 lb per ton of high polyunsaturated fatty-acid mixture
 2.0 lb per ton of Na_2SiO_3

Temperature of pulp: 72° F.

Heat treatment: none

Flotation: 1 stage, 7 min

Results:

Product	Weight (gm)	Zn Assay (%)
Concentrate	193	25.0
Tailing	765	8.4

Ratio of concentration: 1 to 5.18

Percentage of recovery: 39.4 %

Test Z-6

Grind: as in Test Z-5

Temperature of pulp: 74° F. after grinding

Heat treatment: heating to 102° F.

Flotation: 1 stage, 5 min

Results:

Product	Weight (gm)	Zn Assay (%)
Concentrate	328	32.0
Tailing	685	2.2

Ratio of concentration: 1 to 3.35

Percentage of recovery: 85.6 %

Test Z-7

Grind: as in Test Z-5

Temperature of pulp: 74° F. after grinding

Heat treatment: heating to 167° F.

Flotation: as in Test Z-5

Results:

Product	Weight (gm)	Zn Assay (%)
Concentrate	275	35.7
Tailing	677	1.5

Ratio of concentration: 1 to 3.64

Percentage of recovery: 30.1 %

Test Z-6

Grind: as in Test Z-5

Temperature of pulp: 72° F. after grinding

Heat treatment: heating to 180° F.

Flotation: as in Test Z-5

Results:

Product	Weight (gm)	Zn Assay (%)
Concentrate	315	53.8
Tailing	675	1.6

Ratio of concentration: 1 to 3.18

Percentage of recovery: 37.0 %

Test Z-9

Grind: 1000 gm of synthetic ore
for 8 min in ball mill with
1000 ml of tap water

Temperature of pulp: 74° F.

Conditioning: 5 min with
1.2 lb per ton of CuSO₄
3.0 lb per ton of CaO
3 min with
0.05 lb per ton of pentasol xanthate
4 drops of pine oil

pH of pulp: 10.5

Flotation: 1 stage, 4 min

Results:

Product	Weight (gm)	Zn Assay (%)
Concentrate	180	58.7
Tailing	820	2.7

Ratio of concentration: 1 to 5.56

Percentage of recovery: 86.3 %

1-10

Genetic length: 2.41 Mb (2-9)

Read coverage: 100x to 1.0⁶

Directions: 1 step

Results:

Accession	Size (nt)	Length (nt)
Gene structure	117	1.0
5' UTR	101	1.1

Multiple sequence alignment: 1 to 1.0

Percentage of coverage: 99.5 %

Test Z-11

Grind: as in Test Z-9

Conditioning: as in Test Z-9

Heat treatment: heating to 167° F.

Flotation: 1 stage

Results:

Product	Weight (gm)	Zn Assay (%)
Concentrate	187	56.4
Tailing	812	1.8

Ratio of concentration: 1 to 5.35

Percentage of recovery: 86.1 %

Test Z-12

Grind: as in Test Z-9

Conditioning: as in Test Z-9 but pH 11.4

Heat treatment: heating to 130° F.

Flotation: 1 stage

Results:

Product	Weight (gm)	Zn Assay (%)
Concentrate	140	48.2
Tailing	730	5.1

Ratio of concentration: 1 to 7.15

Percentage of recovery: 55 %

Test Z-13

Grind: 1000 gm of Gilman ore
for 10 min in ball mill with
666 ml of tap water

Temperature of pulp: 69° F.

Desliming: none

Conditioning: after galena flotation and correction
of pH to 11.0, the following reagents
were added:
1.25 lb per ton of CuSO_4
0.04 lb per ton of potassium amyl
xanthate
4 drops of pine oil

Heat treatment: none

Flotation: 1 galena flotation stage
1 marmatite flotation stage

Results:

Product	Weight (gm)	Zn Assay (%)
Galena concentrate	52	14.1
Marmatite concentrate	197	41.3
Tailing	600	1.7

Page 1-2. (cont'd)

Percentage of recovery on read: 65.

Test Z-14

Grind: as in Test Z-13

Desliming: yes

Conditioning: as in Test Z-13

Heat treatment: heating to 122° F.

Flotation: as in Test Z-13

Results:

Product	Weight (gm)	Zn Assay (%)
Galena concentrate	125	14.95
Marmatite concentrate	175	38.15
Tailing	665	3.7

Percentage of recovery on feed: 55.4 %

Percentage of recovery on pulp: 62.7 %

Test Z-15

Grind: as in Test Z-13

Desliming: yes

Conditioning: After galena flotation and correction of pH to 10.9 the following reagents were added:
 1.25 lb per ton of CuSO_4
 0.10 lb per ton of potassium amyl xanthate

Heat treatment: heating to 167° F.

Flotation: as in Test Z-13

Results:

Product	Weight (gm)	Zn Assay (%)
Galena concentrate	85	12.7
Marmatite concentrate	155	23.8
Tailing	638	10.2
Slimes	90	7.85

Percentage of recovery on feed: 29.5 %

Percentage of recovery on pulp: 34.3 %

Test Z-16

Grind: as in Test Z-15

Desliming: yes

Conditioning: as in Test Z-15 but using
0.3 lb per ton of potassium amyl
xanthate

Heat treatment: as in Test Z-15

Flotation: as in Test Z-15

Results:

Product	Weight (gm)	Zn Assay (%)
Galena concentrate	75	14.7
Marmatite concentrate	183	19.0
Tailing	677	10.25
Slimes	38	8.9

Percentage of recovery on feed: 27.8 %

Percentage of recovery on pulp: 31.4 %

Galena Flotation Tests

For these tests a synthetic galena ore and a natural galena ore were used. The synthetic ore was made up of 10% galena jig concentrate, containing 86% lead, and 90% clean washed Clear Creek sands consisting primarily of inactive quartz and feldspar.

The natural ore, from the tri-state district (St. Joseph Lead) was constituted of about 15% lead as galena with gangue minerals consisting primarily of silicified limestone.

The reagents used were pine oil and Aerofloat 31.

Test P-1

Grind: 1000 gm of synthetic ore
for 8 min in ball mill with
1000 ml of tap water

Temperature of pulp: 66° F.

Heat treatment: none

Flotation: conditioning for 5 min with
4 drops of pine oil;
stages, 1; flotation time, 5 min

Results:

Product	Weight (gm)	Pb Assay (%)
Concentrate	41	54.3
Tailing	965	6.7

Ratio of concentration: 1 to 24.4

Percentage of recovery: 36.4 %

Test P-2

Grind: as in Test P-1

Heat treatment heating to 122° F.

Flotation: as in Test P-1

Results:

Product	Weight (gm)	Pb Assay (%)
Concentrate	68	67.6
Tailing	930	4.1

Ratio of concentration: 1 to 14.7

Percentage of recovery: 53.5 %

Test P-3

Grind: as in Test P-1

Heat treatment: heating to 154° F.

Flotation: as in Test P-1

Results:

Product	Weight (gm)	Pb Assay (%)
Concentrate	86	74.4
Tailing	903	2.0

Ratio of concentration: 1 to 12.8

Percentage of recovery: 64 %

Test P-4

Grind: 1000 gm of St. Joseph Lead ore
for 10 min in ball mill with
1000 ml of tap water

Temperature of pulp: 68° F.

pH of pulp: 8.7

Heat treatment: none

Flotation: conditioning for 4 min with
0.5 lb per ton of Na_2SiO_3
5 drops of pine oil
stages, 1; flotation time, 4½ min

Results:

Product	Weight (gm)	Pb Assay (%)
Concentrate	22	37.8
Tailing	957	0.75

Ratio of concentration: 1 to 45.5

Percentage of recovery: 55.6 %

Test P-5

Grind: as in Test P-4

pH of pulp: 8.7

Heat treatment: heating to 122° F.

Flotation: as in Test P-4

Results:

Products	Weight (gm)	Pb Assay (%)
Concentrate	28	25.3
Tailing	970	0.5

Ratio of concentration: 1 to 35.7

Percentage of recovery: 59.3 %

Test P-6

Grind: as in Test P-4

pH of pulp: 8.5

Heat treatment: heating to 162° F.

Flotation: as in Test P-4

Results:

Product	Weight (gm)	Pb Assay (%)
Concentrate	22	20.8
Tailing	957	0.8

Ratio of concentration: 1 to 45.5

Percentage of recovery: 37.4 %

Test P-7

Grind: 1000 gm of St. Joseph Lead ore
for 10 min in ball mill with
1000 ml of tap water
3 drops of Aerofloat 31

Temperature of pulp: 62° F.

pH of pulp: 8.5

Heat treatment: none

Flotation: conditioning for 3 min with
0.5 lb per ton of Na_2SiO_3
stages, 1 rougher; flotation time, 6
min

Results:

Product	Weight (gm)	Pb Assay (%)
Concentrate	44	37.3
Tailing	953	0.3

Ratio of concentration: 1 to 27.5

Percentage of recovery: 89.4 %

Test P-8

Grind: as in Test P-7

pH of pulp: 3.5

Heat treatment: heating to 122° F.

Flotation: as in Test P-7; flotation time, 7 min

Results:

Product	Weight (gm)	Fb Assay (%)
Concentrate	52	29.7
Tailing	955	0.2

Ratio of concentration: 1 to 19.2

Percentage of recovery: 39.4 %

100%

100% of 100%

100% of 100%

Cost	100%	100%
Concrete	100	100
Rebar	100	100

100% of 100% = 100%

100% of 100% = 100%

OBSERVATIONS

1. In all the experiments a change in the appearance of the surface of the pulp was observed, usually when the temperature went above 120° F. This change was markedly noticeable in fatty-acid flotations, particularly those of fluorspar and manganese oxide.

A thick purple layer of large bubbles was noted on the fluorspar pulp; the formation of this layer was accompanied by the rise of the pulp level due to steam formation in the container when the temperature approached the boiling point of water.

A similar layer, but black in color, was noted in manganese oxide flotation. However, the bubbles were smaller than in the fluorspar flotation.

2. The characteristics of the froth obtained after heat treatment -- namely its persistence, size of bubbles, and water content -- are very different from those of the froth obtained by normal-temperature procedure. The froth is dry, particularly in fluorspar and manganese oxide flotation, and the bubbles are much finer and more uni-

form in size.

Heat treatment in fluor spar, sphalerite, and manganese oxide flotation seems to produce extremely persistent froths. After many recleaner operations and frequent additions of cold water, the froth is still heavily loaded with minerals and so abundant that no further additions of collector are needed. This froth characteristic is particularly noticeable in fatty-acid flotation.

3. In xanthate flotation of sphalerite, it was noted that at temperatures around 150° F. the settling velocity of the solids in the pulp is much higher than that at lower temperatures.
4. In Test F-12 the fluor spar ore was ground dry, conditioned with powdered reagents, heated for 1 hour, and then cooled. Upon the addition of cold water to this pretreated ore, a persistent heavily laden fluor spar froth formed immediately, even before any agitation.
5. In all tests, the froth in the rougher stage of flotation was very dirty and the bubbles were somewhat coarse. During the succeeding stages the gangue and the poorer middling particles progressively dropped out.

However, in rougher flotation after heat treatment, the recovery of fluor spar was greatly improved. This is evidenced by the fact that the fluor spar content of the

rougher tailing was much lower than in normal flotation.

Usually, in these fluorspar and manganese-oxide flotation tests, two cleanings were enough to eliminate most of the gangue and low-grade middling particles.

6. The relatively high slime content of the fluorspar and manganese pulps seemingly did not adversely affect the flotation after heat treatment. In comparison, flotation carried out at room temperature gave very poor results, primarily because of the presence of slimes.

CONCLUSIONS

1. The heat treatment of the fatty-acid conditioned flotation pulps of fluorspar, manganese oxide, and synthetic sphalerite ore always produced an increase in the grade of the concentrate and in the percentage of recovery.
2. The heat treatment of the xanthate-conditioned flotation pulp of synthetic sphalerite ore did not produce any remarkable effect. The fact that one of the experiments carried out after heating the pulp showed a very high grade of the concentrate (61.2 % zinc) and a high recovery (88.6 %), does not exclude the possibility that the same results could be also obtained with careful flotation at normal temperature.

The improvement, if any, is very slight, and very careful research should precede any attempt to use heat treatment of xanthate-conditioned sphalerite pulps.

3. The heat treatment of the xanthate-conditioned flotation pulp of a marmatite ore shows a decrease of both the

grade of concentrate and the percentage of recovery as the temperature of the pulp increases above 74° F.

4. The persistence of the froth obtained by flotation of a fatty-acid-conditioned heat-treated pulp might be explained by the theory of Last and Cook ^{4/}.

If adsorption is the physical phenomenon underlying the mechanism of fatty-acid collection, physical adsorption is very likely to occur at normal temperatures (around 70° F.) whereas activated adsorption would occur above a definite higher temperature and after a definite heating time. The fact that physical adsorption occurs at normal temperatures can be derived from the observation that after one cleaning more collector is needed. This addition evidently has to make up for the collector washed away from the particles. This means that collection at normal temperature is a reversible phenomenon.

On the other hand, activated adsorption is described as taking place at high temperatures and being irreversible. The assumption that activated adsorption takes place after heat treatment is substantiated by the persistence of the froth.

5. The increase in the grade of the concentrate after the first cleaner suggests the existence of a more selective collection at higher temperatures.

The activated adsorption would occur principally on the valuable minerals, whereas the physical adsorption would occur on the gangue, which in the tests usually contained high percentages of silica and limestone.

This selective adsorption cannot be entirely attributed to a different affinity of the same collector to different minerals. Even though a certain collector undoubtedly has different collecting power for different minerals, certain factors cannot be neglected.

First, dispersants and gangue depressants (like sodium carbonate, sodium silicate and Quebracho) have a large influence.

Second, if the collecting mechanism is based on activated adsorption, which is a phenomenon of the same type as catalytic reaction, the valuable minerals, or the minor constituents of the ores, or the dispersants and depressants might have such a "poisoning" effect on the limestone or silica surfaces as to render impossible the occurrence of activated adsorption of fatty-acid molecules on them. Therefore, the only possible adsorption on these gangue particles would be physical adsorption, and this type of adsorption decreases with the increase of temperature.

6. One of the most important effects of heat treatment of the pulps is that, whenever an increase of temperature produces

an improvement in flotation, desliming is not necessary, even if the pulp has a high slime content. Desliming becomes undesirable because of the large loss of valuable ore.

The harmlessness of slimes in flotation of heat-treated pulps can be explained as follows: the Brownian movement is faster at high temperatures and (a) produces a strong dispersion, with consequent detachment of even the finest particles from one another and liberation of the valuable ones from the gangue; (b) increases the probability that the mineral particles will meet a fatty acid molecule and be coated.

7. The collecting power of fatty acids is very clearly related, as stated by Hukki and Vartianen ^{2/}, to the number of double bonds present in the molecular chain. The results obtained in the flotation of sphalerite synthetic ore and of the very difficult manganese oxide further show that the increase of fatty-acid collecting power after heat treatment is greater for high polyunsaturated fatty-acid mixtures than for low.

In manganese-oxide flotation a pulp conditioned with oleic acid and then heated does not show any collection, whereas a pulp given the same treatment with high polyunsaturated fatty-acid mixture does show collection.

8. As a consequence of the preceding conclusion, it appears that the collecting power of fatty acids is closely related to their degree of unsaturation. In turn, the last statement could be explained by assuming that secondary valences of the double bond are excited by heating and that it is these secondary valences which play the major role in the activated-adsorption phenomenon of collection.

9. Heating of xanthate-conditioned marmatite pulp above 74° F. results in a poorer flotation.

As the temperature increases, both grade of concentrate and percentage of recovery decrease. Consequently, it may be supposed that the collecting process (1) is of a different type than adsorption, or (2) is based on physical adsorption only, or (3) is altered by the occurrence of soluble salts in the ore.

10. The coating of fluor spar with fatty acids does not require the presence of water.

The heat treatment of a dry-ground pulp conditioned with powdered reagents seemingly still produces an increase of the grade of the concentrate, although the recovery is lower than that obtained from the flotation of wet-ground pulp. This result could be taken as a confirmation of the fact that the mechanism of collection is related to the molecules of the fatty acid rather than to its ions 4/.

The fact that the collection occurred even after the ore was cooled might be taken as a demonstration of the irreversibility of the collection process.

The two last conclusions are therefore in agreement with the hypothesis of molecular adsorption proposed by Cook and Last ^{4/}, of which no satisfactory physical demonstration has previously been given.

11. The flotation of manganese oxide is very difficult because of the very fine association with the gangue minerals. A grinding to minus 400-mesh does not produce complete liberation.

Even though these experiments were far from yielding any concentration of practical value, they were carried out in order to obtain some indication of the effect on manganese oxide flotation of heat treatment as compared with conventional room-temperature flotation.

The tests performed show that oleic acid and low polyunsaturated fatty-acid mixture do not collect the ore, even after heat treatment.

A high polyunsaturated fatty-acid mixture and heat treatment of a pulp ground very finely produce some degree of collector coating and selective flotation of manganese oxide.

Even though a commercial grade is not obtained, this constitutes a clear indication, or trend, which might be investigated by further research.

12. Tests from P-1 to P-6 were performed without using any reagent other than pine oil.

The first three tests, in which a synthetic ore was employed, show that, as the temperature increases, both grade of concentrate and percentage of recovery increase.

The latter three tests, performed on St. Joseph lead ore show exactly opposite results.

From the first three tests it clearly appears that the spontaneous floatability of galena increases with temperature and is a property intrinsically related to the mineral itself.

This result suggests the idea that temperature not only influences the mechanism of collection by itself but also produces an activation in the mechanism of bubble attachment whenever a mineral surface is collector-coated.

This last statement is not contradicted by the results obtained in the other three above-mentioned tests: the increased activity of the galena surface makes it more readily "poisonable" by chemical compounds like soluble salts probably present in the natural ore.

The heat treatment of galena pulp conditioned with Aerofloat 31 did not produce any remarkable effect. The same remarks made in conclusion 2 can be applied to this case.

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