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MSM
HISTORICAL
COLLECTION

THESIS

—FOR—

Degree of Bachelor of Science

—IN—

Mining Engineering,

—BY—

Albert E. Eardley and John S. Cameron.

SUBJECT:

"Hydraulic Separation."

7662

MSM
HISTORICAL
COLLECTION

Thesis for degree of Bachelor of Science
in
Mining Engineering,
by
A. E. Eardley and John S. Cameron,

Subject,

Hydraulic Separation.

Before beginning a discussion of the various experiments performed with the hydraulic separators in the Laboratory of the S. of M., a brief statement as to the principle upon which their working depends, and their functions in the dressing of ores should be given.

The crude ore when first delivered from the mine is usually not of sufficient richness to be economically handled by the smelters; it therefore becomes necessary to eliminate as far as possible that part of the ore which is of no material value, and among the various forms of apparatus now in use for this purpose the hydraulic separator plays a very important part.

When ores are concentrated by any means whatsoever there are always two chief factors that enter into the problem, viz: specific gravity and the relative size of the particles. In order that a jig may have fed to it material containing equal settling gangue and ore, with all intermediate grades of ore from those of equal diamater with a fixed maximum size of gaugue to the size which is to be equal settling with a fixed minimum size of gaugue, so that there shall be, within proper economical limits, three grades of ore in the mass fed onto the jig screen, viz:- one grade which will not be lifted with the ascending current, one which falls through the interstial spaces, and partly, with the unavoidable 3rd, grade of fines, will be drawn through the ore bed by the suction at the end of the jig cycle - in order to accomplish this it is usual in the best modern practice to give the ore a preliminary dressing in some form of hydraulic separator.

The principle upon which the working of hydraulic separators depends is the relative rate of fall of the particles of an ore mixture in water. When a body falls in still water it falls at first with an accelerated velocity, its weight being the constant force ever tending to increase its velocity, and its velocity will be thus constantly increasing until the resistance of the water counteracts the force producing motion, it will then fall with uniform velocity.

The laws governing the fall of bodies in water have been fully investigated by Von Rittinger and in any subsequent discussion in finding the rates of fall of galena, limestone or quartz in water, his formula will be used in their determination.

Von Rittinger in his laws of bodies falling in water states that,

$V^2 = c.\ d.$

V. = Velocity of fall of particles

d. = diameter of particles

c. = a constant depending upon the specific gravity of the particles.

The different rate of fall of particles of an ore mixture consisting of particles of different specific gravity and different size gives us a method whereby a separation can be accomplished, because a rising current of water that will just carry over the lighter particles of the ore, cannot have velocity enough to prevent the sinking of the heavier particles.

Based upon this principle hydraulic classifiers are today employed in the preparation of ores for further concentration and in every one a rising current of water is depended upon to achieve the object sought.

The difficulties encountered with the types of hydraulic separators in use today will be discussed later when the experiments with the separator in the Met. Laboratory are described.

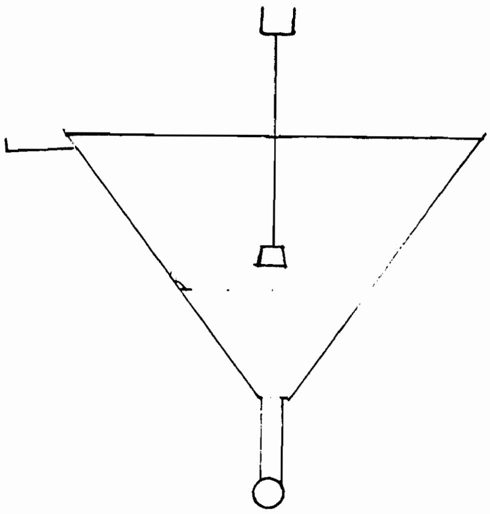
The first experiments attempted were with the Inlet discharge separator. Fig. 1 shows the arrangement of apparatus for making the experiments.

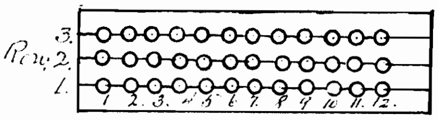
A is a launder through which the pulp flows into the separator B.; C. is a barrel which was suspended from the ceiling and could be raised or lowered at will; D. is a valve for admiting and shutting off water from the separator.

As will be seen from the diagram the pulp enters the separator through the launder A. and meets a rising current which enters at the bottom of the separator. The object of the experiments with this separator were to determine the size of the material which it could handle, and the degree of concentration that could be obtained with it.

In order to understand more clearly the action of the water on the ore particles in the separator a device for obtaining the pressure of the water in different parts of the separator was devised.

It consisted of a cork one inch high by 3/4 inches in diameter bored out in the center and loaded with shot until its specific gravity, was just equal to that of the water. In the top of the cork was inserted a thin glass rod 15 inches long which passed through a short glass tube as a guide which was supported on a thin board, perforated with holes one inch a part, that covered the top of the separator.





The cork was placed in the separator and the rod passed through the guide which was placed in some particular hole. The rising current was then turned on and weights were placed in the cup until the cork assumed any height desired in the separator. It was then moved to the next hole and the cup weighted until the cork stood at the same height as it did in the previous position. After the pressure of the water in the various positions in the separator at some particular height had been found, the pressures at some other height were found in the same way.

Data.

2 - 5 means 2nd. Row and 5th hole.

Height 10"		Height 3"		Height 6"		Height 4"	
No. of Hole	Wt.	No. of Hole.	Wt.	No. of Hole.	Wt.	No. of Hole.	Wt
2 - 5	0	2 - 5	0grms.	2 -5	2 grms	2 - 6	313g
2 - 6	7 grms.	2-6	11 "	2 - 6	16 "	2 - 7	48
2 - 7	11 "	2 - 7	16 "	2 -7	23 "	2 - 8	31
2 - 8	7 "	2 - 8	11 "	2 -8	16 "	2 - 9	8
2 - 9	0 "	2 - 9	0 "	2 -9	2 "	2 - 5	8

See page No 6.

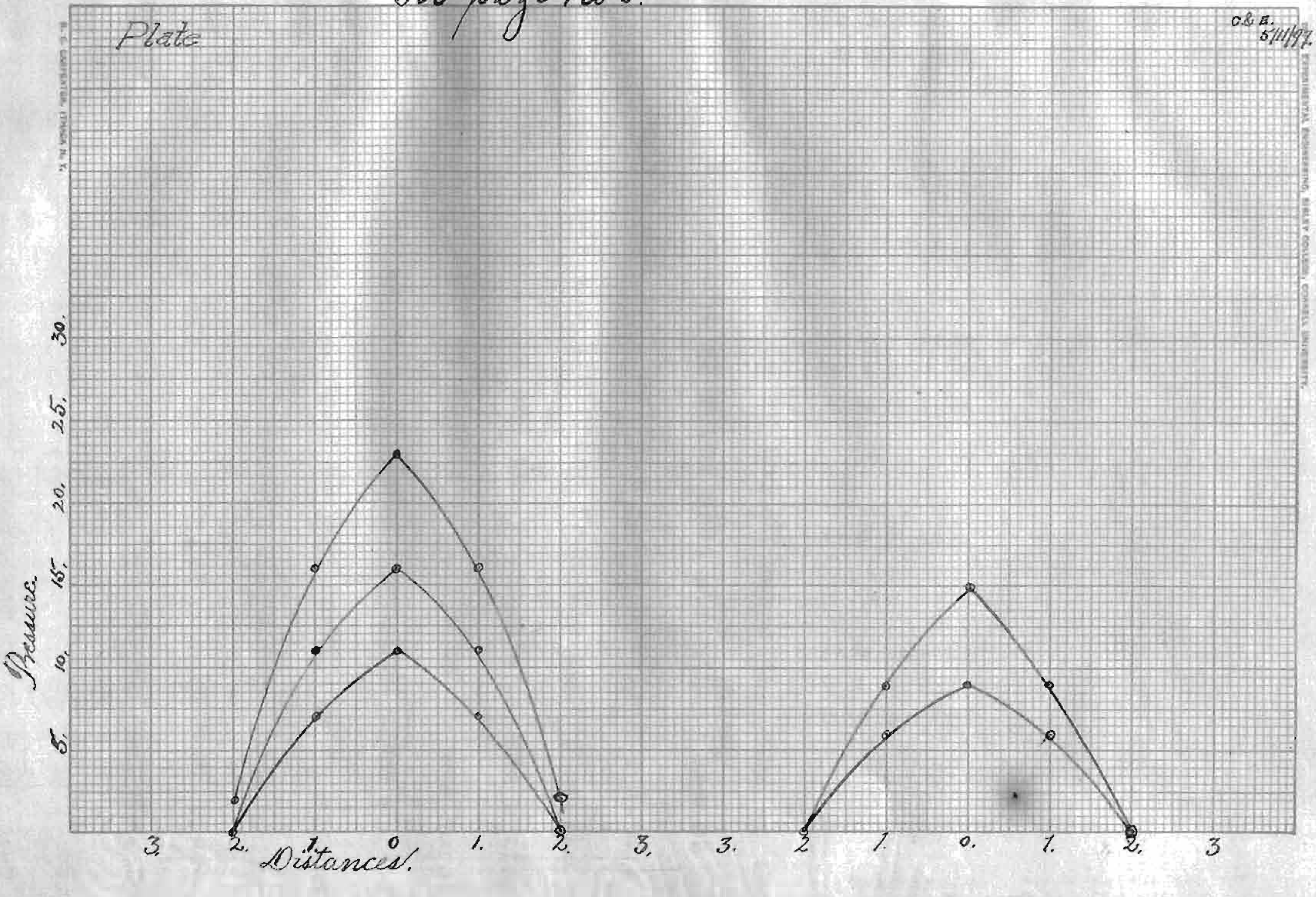


Plate
C.& E.
5/11/97.
EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY.
B. C. CARPENTER, ITHACA N. Y.
Pressure.
30.
25.
20.
15.
10.
5.
3.
2.
1.
0
1.
2.
3.
3.
2
1.
0.
1.
2.
3
Distances.

Data

Height 10"		Height 8"		Height6"	
No. of Hole.	Wt.	No. of Hole.	Wt.	No. of Hole.	Wt.
1 - 5	0 grms.	1 - 5	0	1 - 5	3
1 - 6	6 "	1 - 6	9	1 - 6	20
1 - 7	9 "	1 - 7	15	1 - 6	30
1 - 8	6" "	1 - 8	9	1 - 7	20
1 - 9	0 "	1 - 9	0	1 - 8	3

The pressures in Row #3 ~~under~~ were the same as those in #1

The amount of water used per minute was 65 pounds which through a one inch orifice gives nearly a one foot head.

If now the distances from the center of the orifice are plotted as abscissas and the pressures on the bottom of the cork as ordinates we obtain a series of curves herein attached. The general form of these curves at once suggests that they are parabolas but owing to our inability to secure ample and more accurate data this cannot be proven. One thing however is very noticable, viz:- the small volume of space in the separator that is affected by the rising current, not more than 2"inches on each side of the center of the orifice through which the rising current is admitted being thus affected.

The action of the rising current upon the ore when fed into it will be at once apparent when it is remembered that the feed launder does not discharge directly over the rising current but at the end of the separator. The ore after leaving the launder falls directly into the end of the separator and continues to fall until it encounters the rising current when particles too light to stem the tide are difted up and carried over the discharge by the outflowing water, while particles too heavy to be carried upward fall and are finally carried ~~up~~ off through the spigot.discharge.

After the above experiments were performed, lots of ore of different sizes were fed into the separator and the amount of water and time required for separation were noted, samples of tails and concentrates being taken and the degree of concentration and size of material classified, determined. Lead ore from Mine LaMotte and Bonne Terre, Missouri was used in all the experiments. A convenient and rapid method for calculating PbS in an ore carried in a gangue of uniform sp. G. is as follows:-

Let a = Wt of ore mixture in air
b = " " " " water
c = Specific gravity of PbS - 6.75
d = " " " CaCo 3 - 2.72
x = Wt PbS in mixture

then

$$x = \frac{d\,c\,a - d\,c\,b - a\,c}{d - c}$$

This formula was taken from Prof. P. DeP. Ricketts' Notes on Assaying.

The first ore that was fed to this separator varied in size from 16 to 30 mesh inclusive. As great a head as could be safely used would not discharge any material over the tail overflow, neither were there any concentrates discharged. This result, although it may seem remarkable, is quite easily explained. As was shown in a previous experiment the space in the separator affected by the rising current was comparatively small and the ore, although carried upward by the rising current, would rise until forced into some space where there was no current or would be carried to the surface of the water only to be thrown down against the sides of the separator by the downward current of water after it had reached the surface as is shown in Fig. 2.

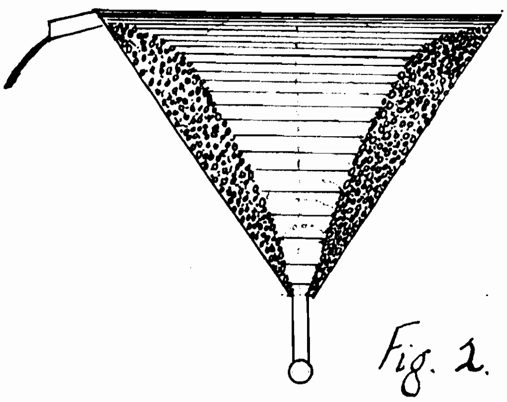


Fig. 2.

The velocity of the rising current was so great that not even the heavier particles of the ore could fall through it and be discharged. The ore then banked up on the sides of the separator until it became so full that no water could ascend through it, but forced itself through the small orifice through which the concentrates discharge, the force of the water in the tube leading upward into the separator being great enough to hold the ore in suspension but not great enough to cause the lighter particles of the ore to overflow. From the above result it would seem that no concentration or separation can be affected by feeding ore coarser than 30 mesh to this separator. 50 pounds of ore finer than 30 mesh was next fed after determining the proper head to allow all material finer than 60 mesh to fall through the rising current.

Data.

Amt. ore Fed.	Kind.	Amt. Tails.	Amt. Heads.	PbS in tails.
50 lbs.	Finer 30.	19.5 lbs.	30.5 lbs.	8%.
30	" 40	14 "	16 "	11.2%.
30	" 50	13 "	14 "	12.34.

Amt. ore Fed.	PbS in heads.	PbS in ore.	Time req.	Amt Water.
50 lbs.	42.3%	22.75%	5 min.	9 1/2cu.ft
30 "	36.43%	22.54%	2 3/4 "	6 " "
30 "	35.27%	23.2%	2 3/4 "	5 3/4 " "

The tails from the above experiments were all very fine and judging from their appearance were in good condition to be further treated by contact plane concentrators. The heads, as seen from the table, were quite rich and exhibited a fairly uniform size although there was considerable fines in them. The quantity of water used is great considering the amount of ore treated and a much greater head than that ascertained by Von Rittinger's formula was required before any separation could be affected, in fact the head required to separate any given material is a matter of experiment with this separator as a large portion of the feed water is used in discharging the concentrates, also the form of the separator makes it impossible to affect a separation and discharge the tails without a much greater head than that which theoretically should affect the separation.

The next experiments performed were with the Calumet classifier. The form of this classifier is shown in plate two. In practice it consists of four or five boxes or depressions, 11 inches deep, in a bottom of a continuous trough. The rising current is delivered from a pipe which enters near the bottom of each compartment. The pipe leads in clear water which finds its way into the classifier through several small holes one quarter inch in diameter bored through the top of the pipe. Directly opposite the end of the inlet pipe is a pipe for discharging the concentrates. In practice, as has already been stated, there are four or five boxes and the separator is made of wood. In the experiments performed with this type of classifier but one compartment was used and glass sides were substituted for the wooden sides in order that a more careful study could be made of the action of the rising current on the ore particles when fed into it. A one compartment classifier with glass sides was constructed in the Metallurgical Laboratory and the first experiment consisted in finding the pressure of the water in the separator. The same apparatus that was used in finding the pressure of water in the Inlet discharge separator was here employed and the experiment was performed in the same way.

Data. pressures 4" from top of feed pipe and 5" from side separator.

Pressure.	Hor. dist. from center line of feed pipe.
34 grams.	0"
25 "	1/2"
13 "	1"
0 "	1 1/2"

Pressures 4" from top of feed water pipe and 7" from concentrate discharge side of separator.

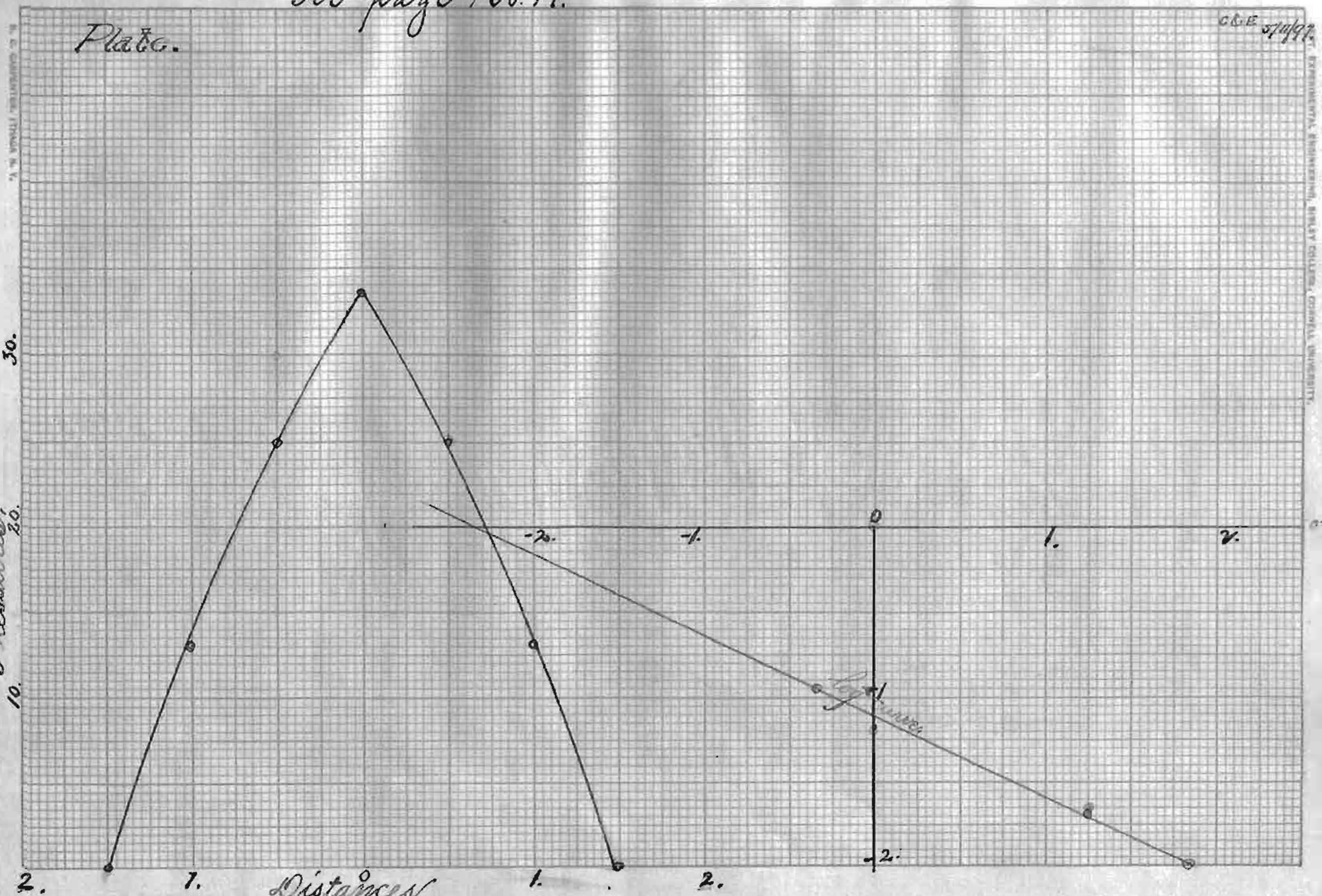
Pressure	Hor. dist. from center line of feed pipe.
35	0
24	1/2
13.5	1
0	1 1/2.

No pressure could be detected by our apparatus in that part of the separator above the shield that covers the concentrate discharge neither were there any pressures found on either side of this shield.

If now the distances from the center line of the feed water pipe are plotted as abscissas and the correspodning pressures as ordinates we obtain a curve shown in plate #2. From the shape of the curve we may assume it to be a parabola and its equation will be of the form $(y-c) = K X^n$ the center being at the point (0, c) where c equals 34. Transferring the origin to the point (0, 0.) the form of the equation reduces to $y = k x^n$. Taking the logarithm of each side of this equation we have

$$\log y = \log K + n \log X.$$

See page No. 11.



This is the equation to a straight line in which n is its slope.

P - 34	L.	log (P-34)	L.
0	0	0	+ 0
-9	1/2	-.96	1.7
-19	1	-1.18	0
-34	1 1/2	-1.63	1.18

plotting log (P-34) and log L we obtain a straight line and by measurement its slope is 1/2. Therefore the equation to the curve becomes $y = k\ x^{1/2}$.

Here again the amount of data obtained is small and although the pressure of the water at distances of 5 inches and 7 inches, from the concentrate discharge side of the separator, show a fair degree of uniformity there were many ways in which errors crept into our work and at best we can but say that the data obtained are only a rough aproximation of the truth. We feel however that the above results prove that, with proper apparatus and experimentation, the variation in pressures of the rising current inside the separator can be studied successfully.

After the above experiment was finished, accurately sized ore was fed into this separator to determine the degree of concentration that could be obtained with it, its value as a sizer being determined in a subsequent experiment.

Data.

Size of ore.	% PbS in ore.	% PbS in heads.	% PbS in tails.
24 mesh	30.5	47.5	----------- --
40 "	30.5	48	7.5
50 "	30	54	7.5
60 "	24	50.5	14.5
Finer than 60	23.5	84	19.9

% PbS in right end.	% PbS in left end.
7.5	42.5
19.5	40
19.5	76.5
30.5	76.

From the above table it will be seen that a fair degree of concentration was obtained with this separator. When 24 mesh material was fed to the separator no tails whatever came over the tail discharge and the concentration obtained was due to the small amount of PbS in the material that banked up in the right end of the separator. This material, however, increased in richness as the size of the ore fed was decreased as is shown by the table. When material is fed to this separator it does not ~~being~~ begin to discharge the concentrates until a certain amount of ore has banked up on each side~~s~~ of the feed water pipe, the angle of inclination of the banks varying with the size of the material that is fed. Fig. 3 is a sketch showing the angles of inclination of the banks formed when different sized material was fed to the separator.

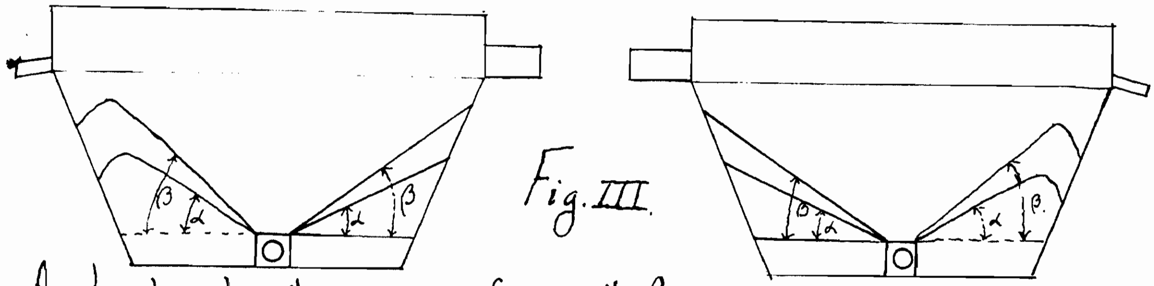
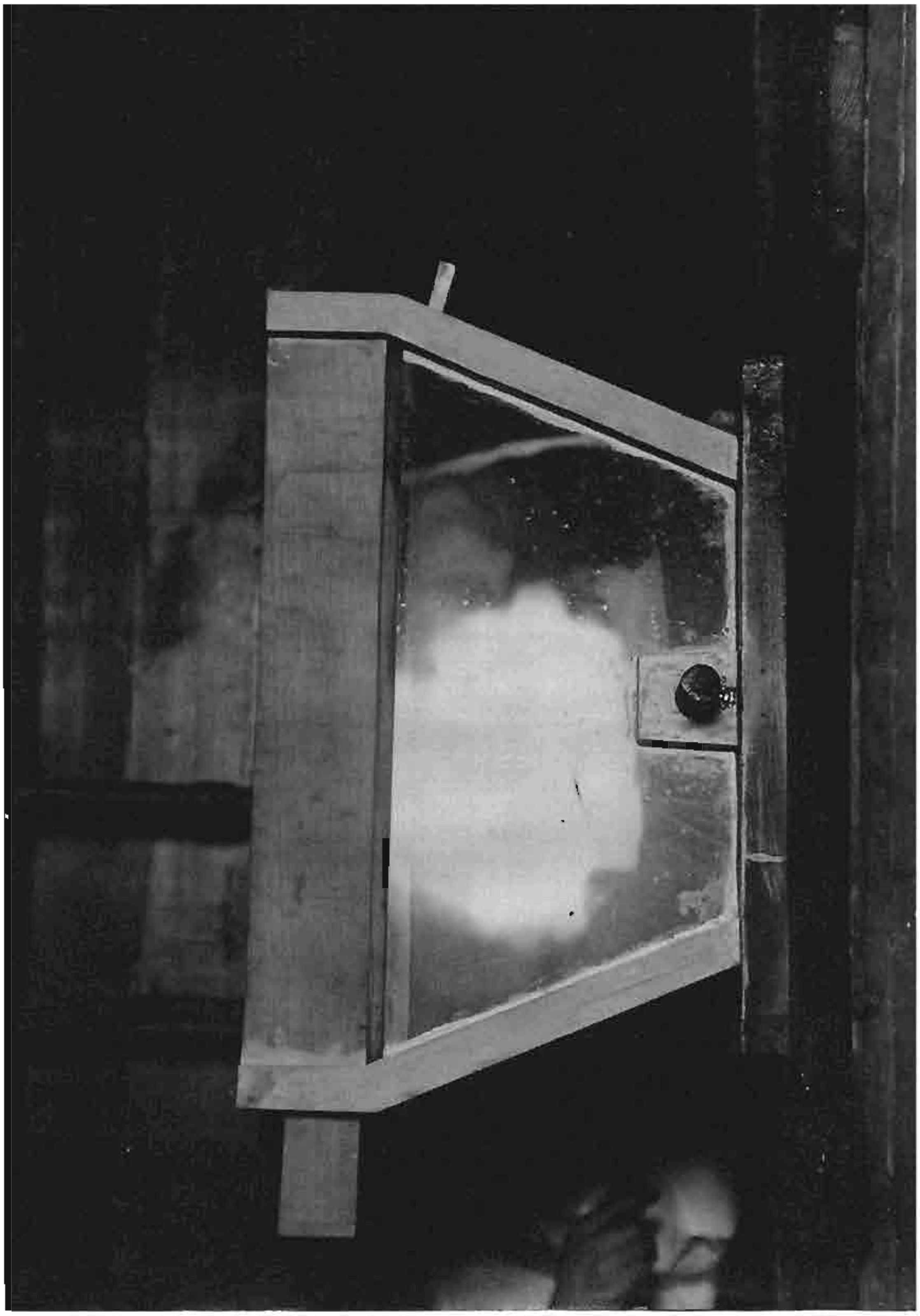


Fig. III.

Angle of inclination varied from α to β as ore fed varied from 16 to 40 mesh.

This angle was found to be the least, the larger the size of ore and to increase as the size of ore decreased. The curved form of the bank on the tail discharge end of the separator was caused by the water not having force enough to throw the particles against the end of the separator, the higest point of the curve being the maximum distance the ore was thrown by the deflection of the rising current. The cause of this curve forming is due to one of two things; The permissible head of water is either insufficient or the separator is badly proportioned. The head of water in our experiments was about 6 feet; much greater than the theoretic head required to separate Galena and Limestone, the fault would therefore seem to be in the design of the separator.

In order to see the direction of the rising current in the separator when in working order a milk of lime solution was used as feed water and after filling the separator with clear water this white solution was turned on and photographed immediately after it had reached the surface of



the clear water in the separator. We attach hereto one of the photographs of the milk of lime solution rising from the feed water pipe into the separator.

After investigating the working of the Inlet discharge and Calumet separators it was apparent that improvement over either of them was quite possible, for in neither do we treat ore under ideal conditions, viz:- a body of ore descending vertically and meeting a vertically rising current of water, the ore being continuously under the action of the rising current until a separation is accomplished.

The amount of water used per ton of ore treated is excessive in these separators, and their capacity per diem is limited.

With these difficulties in mind the task of designing a new separator, that would eliminate to some extent the faults of the two heretofore described, was undertaken. The result of our efforts is shown on plate 3. Here we have a separator that treats ore under the ideal conditions stated, and as will be proven hereafter, a separator that requires much less water per ton of ore treated and with a greater capacity per diem.

Referring to plate 3 it will be seen that it consists essentially of a tube P, 4" in diameter extending into a double cone a distance of 12" and rising 8" above the top of the upper truncated cone. The feed water enters through the pipe E which in no way disturbs the action of the rising current, and the ore is fed in through a hopper B and falls vertically through a pipe 0 1-1/2" in diameter. The pipe extends into the tube P a distance of 8". At the bottom of the lower cone is a small orifice F for the discharge of the concentrates. The ore is fed through the hopper B whence it falls through the feed pipe O and meets the rising current ascending in the tube P. when particles too light to fall through the current will be carried over and discharged.

The maximum size of material that this separator was designed for was ore that would pass through a #12 mesh screen.

Diameter of 12 mesh material = .0613" = .00155 meters

Sp gravity of quartz = 2.6

then by Von Rittingers' formula we have

$$V = 2.44 \sqrt{d(\Delta - 1)},$$

substituting the proper values for d and Δ we get

$$V = 2.44 \sqrt{.00155 \times 1.6},$$

or $V = .123$ meters per second. This velocity will just hold grains of quartz .0613" in diameter in suspension. Now .123 meters = 4.84" per second,

= .403' per second.

Then since the quantity of water passing through any pipe equals the velocity x area we have

$$q = A\,V.$$
$$\text{or} \quad q = 1/3 \times 1/3 \times .7854 \times .403$$
$$\text{or} \quad q = .04 \text{ cu. ft. per second.}$$

When the separator is full of water the head on the discharge orifice is 28" therefore the quantity of water that will be discharged through this orifice will be

$$q = .25 \times .25 \times .7854 \times 2.33$$
$$q = .0056 \text{ cu. ft. per second.}$$

therefore total quantity of water necessary per second = .04 + .0056 = .0456 cu. ft. Now if the head we have to work under is 9' we have

$$q = a\sqrt{2gh} = \frac{\pi d^2}{4}\sqrt{2gh}.$$
$$\text{or} \quad .0456 = \frac{3.1416 \times d^2}{4}\sqrt{64.32 \times 9}.$$

solving this equation for d we obtain as the diameter of feed water pipe necessary to supply the required amount of water. From the equation d = .6".

Now as head required in practice is always much greater than the theoretic head and allowing a small loss for friction and elbows a pipe 1" in diameter was used for the feed pipe.

After the separator was designed and built, a number of tests were made with it the results of which are appended below. The material fed to the separator consisted of lots of ore finer than 12 mesh, finer than 16 mesh, finer than 20 mesh, finer than 24 mesh, finer than 30 mesh and finer than 40 mesh.

Data.

Ore Fed.	PbS in ore.	PbS in heads.	PbS in tails.
Finer than 12	16%	38.4	5.4
" " 16	15.1%	40.5	5.15
" " 20	13 %	43.2	4.95
" " 24	19%	41.4	5.1
" " 30	11.5%	32.1	8.24
" " 40	14%	30.4	12.25

Table showing size of material in ore fed New Separator.

Ore.	% 16 Mesh.	% 20 Mesh.	% 24 Mesh.	% 30 Mesh.
Finer than 12	15	13	10.5	11.2
" " 16	--	7.5	12.5	6.25
" " 20	--	--	9.4	3.65
" " 24	--	--	--	6.66
" " 30	--	--	--	----
" " 40	--	--	--	------

Ore.	% 40 Mesh.	% 50 Mesh.	Finer 50 Mesh.
Finer than 12	10	2.5	37.3
" " 16	17.	2.5	54.25
" " 20	16.9	2.75	62.3
" " 24	15	3.33	75.1
" " 30	5.2	7.00	87.8
" " 40	-- -	10.	90.

Table showing size of material that passed through New Separator

Ore.	%16 Mesh.	% 20.	% 24.	% 30.
Finer than 12	35	20	13.5	11.2
" " 16	--	29	22.	16.
" " 20	--	--	33	31.5
" " 24	--	--	--	43.2
" " 30	--	--	--	----
" " 40	--	--	--	----

Ore.	%40.	% 50.	% Finer 50.
Finer than 12.	11.8	1.4	7.1
" " 16	16	7.2	9.8
" " 20	15.2	9.	11.3
" " 24	30.1	10.	16.7
" " 30	66.6	13.4	30.
" " 40	----	73.4	26.6

The head of water used in obtaining the above results was a matter of experiment as there was no way in which the head could be varied for different sized material, and accurately measured. The valve was opened full for the largest size of ore fed and gradually closed as the size decreased. The results show that the head used when the lots of ore finer than 12 - 16 - 20 and 24 were fed to the separator was, if anything, too small, but the head used for finer than 30 and 40 was excessive as will be seen from the above table.

The results obtained were nevertheless quite satisfactory and the concentrates from the ore finer than 12 - 16 and 20 seemed to be in ideal condition to be further treated by the jig, the tails, though consisting chiefly of fines, contained a much larger percentage of coarse material than was discharged by either of the other separators experimented with.

The next experiment was a comparative test between the Calument and the New Separator designed by us. The same sized material was fed to each and the same head of water maintained for each test so that as nearly the same conditions as possible were aimed at in both cases.

Data.

Separator.	Amt. ore Fed.	Time req.	Amt. Water used.
New Separator.	80 lbs.	3 min.	9 cu. ft.
Calumet.	50 "	4 1/2 "	11 " "

Separator.	Tons ore treated per diem.	Amt. water used per ton.
New Separator.	19.2	222 cu. ft.
Calumet.	8.28	420 " "

Separator.	PbS. in ore.	PbS in heads.	PbS in tails.
New Separator.	16%	38.4%	5.4%
Calumet.	16%	20.2%	6. %

We cannot account for so little PbS being in the tails and for such a small degree of concentration in the Calumet Separator.

Table showing size of concentrates in each test.

Separator.	%16 Mesh.	%20.	%24.	%30.	%40.	Finer 40.
New Separator.	35	20	13.5	11.2	11.8	8.5
Calumet.	17.5	12.5	12.5	10	15	32.5

Amt. concentrates from New Separator - 25 lbs.
" " " Calumet - 28 "

The above results would seem to show at once the superiority of the New Separator over the Calumet in every respect. The most interesting result obtained is the amount of water used per ton of ore treated by each separator, the Calumet using almost twice as much per ton treated as the new separator, and when the work done by each is compared in the tables just given it is but reasonable to think that in a short time the Calumet will give way to some better separator and thus relinquish its claim of being the most satisfactory one used in America today.

As to the new separator little can be said here as to its future use in the preperation of ore for further concentration. The character of the work it has so far done speaks for itself. In a run made in the Metallurgical Laboratory on Monday, May, 11th, by the Junior ore dressing class, crushed ore from #4 mesh to finest slimes was run through this separator, the concentrates were carried directly by a launder to the jig and the material was in excellent condition for further treatment therein. The tails were sent to the spitz Kasten and the products obtained from the 1st and 2nd compartments were coarse enough to be treated by a jig while that in the 3rd compartment was ideal material for bumping tables. This experiment proved beyond a doubt its adaptability in preparing ore to be further treated by other concentrators.

This finished our series of experiments with hydraulic separators and in conclusion can but say that there is chance for vast improvement over those in use today and if we have succeeded in making any improvement ourselves by the designing of the "New Separator" we shall feel doubly repaid for labor spent thereon.

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--FINIS--

Respectfully submitted

McClaurin

Alex H. E. Eardley,

May 15, 1897