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PNEUMATIC ORE CONCENTRATION

BY

ROBERT WINTERS JOHNSON
and
WALTER WILLIAM WEISSBACH

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

BACHELOR OF SCIENCE IN MINE ENGINEERING

Rolla, Mo.

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Approved by C. R. Forbes
Professor of Mining.

19565

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LIST OF ORIGINAL DRAWINGS

INTRODUCTION.

The concentration of lead and zinc ores by means of air is practically an unexplored field, although the subject is by no means a new one. Considerable research work has been done and several methods, processes and machines have been developed, but little or nothing has been accomplished towards making air separation a success.

The lack of success has been due mainly to two reasons:- (I) That very little has been known about the internal conduct of air currents, and (2) that nearly all methods and machines so far worked out have presupposed the fact that the ore to be separated should not come into direct contact with the air currents.

In this thesis the work will be done under the assumption that air currents act or can be made to act with much greater regularity than has hitherto been supposed. This assumption is based upon the fact that air has a great similarity to water and should act in a like manner within a certain ratio. Air, of which one cubic foot at Atmospheric pressure weighs .0807 of a pound, is one-seven hundred seventy fourth (1/774.4) the density of Water, of which one cubic foot weighs 62.5 pounds. Although this ratio is large, it should at least be diminished if not nullified by working with air which has been compressed, and using it under velocity.

Using these assumptions as facts for experimental purposes it is hoped to be able to prove that the ore can be allowed to come into direct contact with the air currents and be separated in and by them, in a manner very similar to water concentration methods.

PRELIMINARY EXPERIMENTAL METHODS.

In the working up of this thesis there were listed for preliminary experimental work several different methods for the separation of lead and zinc ores from their gangue minerals.

(1) Centrifugal force, acting alone.

(2) Oscillating centrifugal air drums, with rocking screens.

(3) Sloping screens with either, (1) uprising air currents, or (2) suction air currents, or (3) horizontal carrying currents in conjunction with either uprising currents or suction currents.

(4) A series of straight enclosed tubes, one series horizontal and the other series vertical or inclined to it: with carrying currents of air in the horizontal series and uprising currents in the vertical series.

EFFECTS OF SPECIFIC GRAVITY.

To carry out the experimental work upon the several methods it was necessary to take into consideration the specific gravity of the different minerals encountered in the ores upon which the theses work was to be done. These were to consist mainly of Missouri lead and zinc ores from the Joplin and Flat River districts, and had constituents with the following specific gravities.

PbS- (Galena)- 7.4 - 7.6 Sp. Gr.

ZnS- (Blende)- 3.9 - 4.1 Sp. Gr.

FeS_2 -(Pyrite)- 4.9 - 5.2 Sp. Gr.

SiO_2 -(Chert) --2.6 - 2.66 Sp. Gr.

$CaMgCO_3$ -(Dolomite)- 2.8 - 2.9 Sp. Gr.

A study of these specific gravities led logically to the conclusion that unit sizes of each mineral should vary constantly in weight in ratio of their specific gravities. If unit sizes would do this, then all sizes should: and, if the difference in sizes were made small enough, there should be found sizes of each mineral of which the weights would not interlock with the one next smaller in size of the mineral next heavier in specific gravity, or with the one next larger in size of the mineral next lighter in specific gravity.

In proof of this the Tables and Curves, Plate 1 and Table 1, were computed.

METHOD OF SCREENING.

The tables and curves, Table 1 and Plate 1, show that the ratio holds true in a majority of sizes. By interpolating to smaller sizes it would hold true in all sizes. If it were true in all instances it would be ideal; such an ideal condition however, is not necessary since the proportion in which it holds true shows less indeterminates than any present day screening methods will give. Under the results as shown by the tables it was determined to screen as closely as possible to a constant size, in order to have as few indeterminates as possible, and then handle these various sizes as separate ores.

With the facilities at our disposal it was impossible to screen to an exact size so the following method was used. The ore was screened as closely as possible and then the particles of each size were weighed up, one at a time, and those reaching the theoretical weights for that size were saved and the others thrown out. This gave an ideal constant size of each size of each constituent mineral.

PRELIMINARY EXPERIMENTS.

Before proceeding to work out any of the experimental methods as listed, Page 3, glass tubes in sizes from one to four inches in diameter and seven feet long, were set up in a vertical position with air entering through pipes at the bottom of each tube. The purpose of these was to obtain either the pressure of air or the velocity of air necessary to just hold in suspension the mineral particles of each size of each mineral.

Sketch No. 1 shows the arrangement of these tubes.

Method.

A particle was dropped in at the top of a glass tube against an ascending air current which was made stronger or weaker until one was obtained which would just hold the particle in suspension. The exp. failed to return the desired results, however, for two reasons.

(1) No pressure or velocity gauge could be obtained which was so constructed that it would receive the air, register it and pass it on through into the tube.

(2) Air was obtained direct from a compressor and consequently was fluctuating. No pressure reducer was available to maintain an even pressure in the feed line.

CONCLUSIONS FROM PRELIMINARY EXPERIMENTS.

The Ratio of Air to Water.

Although the desired results from the preliminary experiments did not materialize, another was noted. When the ore particles dropped through the ascending air currents, which were at a pressure of not more than ninety pounds and the proportional velocity, their conduct was very similar to that under Hindred Settling in water. This was a partial proof of our original assumption, namely that increase of pressure and the use of the air under pressure and its consequent velocity should bring it more closely to the condition of water. Each additional increase of pressure over that of atmosphere and the increased velocity incident to the higher pressures, which acting upon the mineral particles descending has the same relative effect upon them as would a thicker or more dense fluid, (i.e. water), would increase the density of the air and so diminish the ratio of 1/774.4 to a quantity much smaller.

EXPERIMENTAL WORK.

Since no results were obtained from the preliminary experimental work, the work of carrying out the experimental methods of separation as listed on page three, had to be performed under difficulties as the air currents and velocities necessary for the different sizes of the minerals had to be guessed.

Method 1.

Centrifugal Force, acting alone.

No experimental work upon this method was done owing to the fact (1) that considerable had been done in this line by others with very little success; (2) that the method was dangerous owing to the high pressure and speed of revolution.

Method 2.

Oscillating centrifugal air drums, with rocking screens. (See sketch No. 2).

No experimental work was done upon this method beyond working up the design as it was deemed inefficient. Two disadvantages were (1) that mineral once in the machine could only be removed by stopping, and (2) that it could not take a continuous feed.

These disadvantages were due to the principle upon which it was evolved, namely air tight construction, and, high pressure to make increased density.

Method 3.

(a) Sloping screens with uprising currents.

(See sketch No. 3.)

Very little success attended this method owing to the fact that (1) the minerals break up with uneven faces and when lying upon the screen do not present a compact, smooth face; (2) rather they present crevices and breaks which allow the air currents to escape, so making uneven pressure beneath the ore and consequently uneven sorting.

(b) Sloping screens with suction air currents.

(See sketch No. 3 with addition of "B")

In this method the same difficulties were encountered as in the previous experiment with uprising air currents.

(c) Sloping screens with carrying currents
and uprising air currents.

(See sketch No. 3 with addition of "C")

The results from this method were more of a success since the carrying current removed more of the lighter, gangue particles down the screen and also tumbled the ore particles over one another, thereby closing the air channels in the ore, and allowed the uprising currents to act with greater efficiency. The results were too poor, however, to warrant further experiments.

Method 4.

A series of Straight Enclosed Tubes.

(See sketch No. 4.)

In order to abtain some idea of the action of the different sizes of the minerals in enclosed tubes, so that approximate dimensions for an experimental machine might be obtained, several horizontal glass tubes, two to four inches in diameter and seven feet long, were installed, with air pipe entering at one end and the other end open. The purpose of these was to obtain approximately the points at which the various sizes of each miner mineral were dropped in order to locate the points at which vertical tubes which would act as sorting columns, should be cut in.

With the approximate measurements obtained in this manner a machine was constructed for one size of ore, and consisted of a carrying tube and three sorting columns. (See sketch No. 5.)

STRAIGHT TUBE MACHINES.

An ore was made for use on this machine consisting of an even percent of Pyrite, Blende and Galena, - 1%, 8% and 4% respectively, using ordinary screened material instead of Ideal screened. The separation attending was limited. In constructing the machine one side of each column was made of glass to enable an observer to watch the action, and through these two main difficulties were apparent.

(1) With sufficient carrying current of air to move the ore down the carrying tube the ore was jumped across the mouth of the sorting column too rapidly to fall into it. To remedy this would have required making the sorting column of too great dimensions for the air available,-i.e.-the quantity which under velocity and pressure would just let Galena, Pyrite and Blende particles of the same size being worked with fall into the various sorting columns.

(2) When the uprising currents were made of the right strengths they forced mineral particles which should have fallen into a particular column, against the top of the carrying tube above, and the carrying current took them past along with that particular column's gangue material. In other words, when the two air currents met, neither would act as one alone did; rather they tended to increase the carrying power of the one (the carrying current), and the suspension power of the other (the sorting current), and in such a manner that no definite ratio could be obtained.

CONCLUSIONS FROM EXPERIMENTAL METHOD 4.

Cross - currents in Air.

In studying the facts presented by the experiments on this machine the conclusion was reached that the main cause for the action of the air currents, both in single currents, or when brought into conjunction with another, was due to two reasons.

(1) That the velocity of the carrying current created a suction when passing over the sorting columns. However this was neglible since the currents could be varied to meet the increase of suspension power given the sorting current.

(2) That the air, when released under pressure and velocity into the sorting columns and carrying tubes, set up cross currents within itself which were only partly controlled by ordinary chamber walls.

To verify this further investigations were made with vertical glass tubes. (See sketch No. 6.)

These observations proved the point conclusively , and also showed further why a clean separation in straight columns would be practically impossible.

CROSS CURRENTS IN AIR.

The observations from the investigations with glass tubes may be illustrated as follows. A mixture of Galena and Blende of the same size and obtained by Ideal Screening, (i.e.-screening and weighing) was dropped into the glass column at the top against an ascending current strong enough to just allow Galena to fall through it, when dropped one piece at a time. In action, however, it did not do this. The cross currents in the air formed pockets of lesser pressures and areas of greater press--ures, and by them caused the ores to change their relative positions. Sketch No. 6 will show this clearly.

A and B show the position of two particles, one of Galena and one of Blende, falling as they should according to their weights. A' and B' show their respective positions reversed due to the action of the pockets and areas. The air current was made just strong enough to allow A to fall through and for B to be thrown out at the top. A and B in the sketch show them acting thus; a cross current, however, swept them from this position into position A' and B' where B' (Blende) has fallen into a low pressure pocket, A' has been caught in an area of high pressure, so that B' is falling through and A' is rising. The change indicated by the diagram was not permanent but was a continuous movement, due to the rapidity and irregularity of the cross currents of air.

This study of the cross currents of air showed the necessity for some devise by means of which these cross currents could be broken up, before a successful separation by means of air could be obtained. Instead of there being criss-cross currents present, as the investigation showed, straight currents with constant velocity and pressure were required.

BREAKING UP CROSS-CURRENTS.

Experiments looking towards straight currents as a result had been conducted for some time by Prof. E. G. Harris. In his experiments he made use of baffles set at right angles to the air-current and perforated with holes of various sizes through which the air passed. With these he obatined an medium of success in straightening the currents. Because of his attempts with square baffles and because they could not be applied in these experiments as they would stop the free passage of the ore, the search for some devise which would straighten the currents and at the same time allow the ore to pass freely, had to be more extended. This brought finally the idea of sloping, double baffles, alternating in direction of inclination to the enclosing tube or chamber, and forming in conjunction with the sides of the tube or chamber, a continuous criss-cross channel through which the air current acted. (See sketch No. 7)

A machine was then constructed embodying this baffle-channel arrangement. (Sketch No. 8)

CRISS-CROSS DOUBLE BAFFLE CHANNEL MACHINE.

The first machine built embodying the criss-cross baffle channel arrangement at the first trial gave a concentrate of Galena that was approximately clean. On continuous feed, however, it presented difficulties since it choked and could not rid itself of tailings. The ore used was not an Ideal screening, but an ordinary screening of Galena, Blende and Dolomite mixed together after screening. The machine was so much of an improvement over previous investigations, however, that further experiment along this line was warranted.

These further experiments tended to show that each different mineral (i.e.Galena, Blende, Pyrite) required a different inclination to the perpendicular to obtain the best results. (See sketch No. 9).

COMBINATION MACHINE.

The next step was the combining of these single machines into one which would handle all three minerals. This resulted in a machine consisting of a sloping feed tube connecting three inclined criss-cross baffle sorting columns. (See sketch No. 10 without Angle Plates).

The feed tube action was due to gravity and fed into the first sorting column (Galena column); from this the outflow went into the connecting feed tube and from there fed into the next sorting column (FeS column); outflow from this went into the next connecting feed tube and from there into the next sorting column (Blende); the outflow from here went into the tailings tube and out the end of the machine as tailings.

EXPERIMENTS WITH COMBINATION MACHINE.

Under light feed the combination machine worked well but under continuous feed difficulties became apparent. These were,

(1) If the slope of the feed tube were made sufficient to move the ore by gravity it attained so much momentum that it jumped over the mouth of the sorting column.

(2) The sorting columns choked as in the previous experiments upon single machines.

To obviate the first difficulty, since the sorting column could not be made wide enough as shown in a previous experiment, angle baffle plates were placed above each sorting column in the feed tube (See sketch No. 10, with Angle Plates).

EXPERIMENTS AFTER ADDING ANGLE PLATE TO COMBINATION MACHINE.

With the angle plates in place upon the combination machine, practically all the feed was forced down the first (Galena) sorting column, when continuous feed was used. On light feed a pure concentrate of Galena was obtained from the first (Galena) sorting column; the outflow nearly all falling into the second (Pyrite) sorting column and coming out as a middling product.

Because of these results the combination machine was abandoned. In its place single machines for each mineral, (Galena, Blende, Pyrite) were constructed, and handled with a separate feed. Each would act as a Rougher for the minerals below it in Specific Gravity, separating the heaviest mineral as a concentrate.

EXPERIMENTS WITH SINGLE ROUGHER MACHINES.

With the use of single Rougher machines, the outflow from the first one (Galena) went into a bin and fed from it into a second machine (Pyrite); the outflow from this followed a like course to a third machine (Blende); and the outflow from this machine became tailings.

Under a light feed the machine gave good results for all machines. At no time was a chemical analysis made, but by eye and weight analyses concentrates were obtained varying from 70 to 90 % for Galena to 50 to 70% for Blende. Most of the Pyrites fell in with the Galena from which it was easily separated. The flowsheet following is an average one for this type of Rougher machine. By it will be seen that the rerunning of first concentrates were necessary in some cases in order to obtain best results. (See sketch No. 11)

SINGLE BAFFLE CHANNEL MACHINE.

Under heavy, continuous feed, the single machines showed the same difficulty that the first original baffle columns had shown,- choking since the tailings from each machine could not be removed fast enough to make way for the feed. Also the sloping baffles did not hold the material long enough for perfect sorting, but at times let the entire feed drop through into the concentrates.

Under the conditions and results with which this Rougher machine handled the ore, experimental work was abandoned, and investigations were commenced studying the machine in detail as to correctness of principle, method of feed, sorting points, tailings outflow, and possible middlings outflow.

These investigations showed that a number of vital changes were necessary; not only in method of feeding, taking off tailings, but in handling a middling product and in the internal construction of the machine and baffles. Also changes were found necessary in the method of air piping and air compression.

With these improvements a machine was constructed which under continuous feed gave a clean Galena and Blende concentrates. The Pyrite contents were divided between the Galena and the Blende concentrates, but in no case was the percentage of Pyrites in the Blende greater than that which ordinary water jigging gives.

On a last run with this improved machine the following data was recorded and calculated.

DATA FROM IMPROVED BAFFLE MACHINE.

Feed- 10 tons per 24 hours.

Percent. of ore in feed- (250 gms.)

Galena 8%; Pyrites 4%; Blende-20%.

Percent. of ore contents recovered-

Galena- 98.75% ; Pyrites-24%; Blende-65%;

Percent. of tailings-

Galena- 0% ; Pyrites- 36%; Blende-32%.

Percent. of screenings (From rerun concentrates)(15 gm).

Galena- 1.25%; Pyrites- 2%; Blende- 11.25%

Percent. of Pyrite in Galena and Blende-

In Galena- 1%; in Blende- 2%.

Following is a flowsheet of the last run made showing the number of times necessary to rerun the ore. When concentrates or middlings or tailings were rerun, as feed, they were rescreened to remove any indeterminates. Any run on the machine resulted in indeterminates in the output from the machine since the process, being under both pressure and velocity, recrushed the ore to some extent. (See sketch No. 12).

CONCLUSION

The experiments performed in working up this thesis, and especially those performed with the Imporved Double-Baffle Column Machine brought out the following facts concerning the concentration of ores by means of air currents:

(1) That the use of air under pressure and its incident velocity tends to increase the density of the air and greatly diminish the ratio that Atmospheric air has to water.

(2) That the settling of mineral particles through ascending air currents under under pressure and velocity is very similar to that of Hindered Settling in water.

(3) That the cross currents set up in air currents when released under pressure can be practically removed, or at least controlled, by the use of sloping double baffles alternating in direction of inclination to the enclosing tube or chamber.

(4) That screening to a constant size, or as near to a constant size as practical screening will allow, is necessary to attain good results by air separation.

(5) That screening between each remilling is necessary since the action of the machine recrushes the ore to some extent and produces indeterminates.

(6) That any ore in which the difference in specific gravity between the mineral and the gangue material is greater than two can be successfully treated by air.

The difficulties under which the experiments were performed were the inability to screen to a constant size, and the lack of equipment and facilities,-----especially the lack of pressure reducers and also air gauges so constructed that they would receive air, register its pressure or velocity, and transmit it on through to the air machines. During the work on this thesis such a gauge was worked out, as was also an improved centrifugal roaster and screen, but their details are not pertinent here.

The final improved double baffle column machine which gave a high percentage of values saved on ordinary screened ore was 6" x 6" x 42", and had a capacity of 5 ton to 10 ton per 10 hours.

A summary of the above tabulated facts shows that not only is the air concentration of Lead and Zinc ores possible, but that any ore whose mineral and gangue material have a difference in sp. gr. greater than two can be successfully separated by air. In the Improved Double Baffle Column Machine we believe is a machine which will do this successfully, and also cut down the milling cost and mill floor space in as great a ratio as did the Steam Turbine to the Steam Engine.

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No References.

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