PHASES OF
FINE GRINDING

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(Part of an extended investigation
being carried out at McGill University.)

Department of Mining,
McGill University,
Montreal, Canada.

September, 1934.
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A STUDY OF CERTAIN PHASES OF FINE GRINDING

(Part of an extended investigation being carried out at McGill University.)

The main problem of this investigation was the influence of variations in the speed of rotation of a ball mill on the crushing efficiency. For this purpose use was made of a 3' Marcy Quick-Discharge Mill.

The maximum efficiency was found to be about 39 R.P.M., in close agreement with the claim of the manufacturers.

The range of speeds for the more efficient tests was from 39 to 52 R.P.M., with relative mechanical efficiencies of about 700 to 456 surface units respectively.

An increase in the speed of rotation, over the range investigated, was found to cause a decrease in the grinding efficiency.

The investigation, of which the results are given in this paper, was undertaken by the writer as the recipient of the Dr. James Douglas Research Fellowship and in part fulfilment of the requirements for the Degree of Master of Engineering at McGill University. The work was carried out at McGill University in the laboratories of the Mining Department, under the direction of Professor W.G. McBride, the head of the department, and Professor J.W. Bell, Professor of Ore Dressing.

ACKNOWLEDGEMENTS

The writer wishes to express his appreciation of the assistance and advice given by Professors W.G. McBride, J.W. Bell and O.N. Brown, to whom much credit is due for the work accomplished.

To Professor J.W. Bell especially is appreciation due for his invaluable help in the designing and building of the more important additions to the plant.

It is felt that much credit is due to Messrs. Edward and Hugh McBride, mechanic and assistant, for their help and interest in every stage of this investigation.

The writer also wishes to state that he made full use of the thesis of Mr. J.O'Shaugnessy who commenced this investigation on the efficiency of ball mills in the previous year.

To Mr. Leonard Dewar thanks are due for Photographs numbers 4 and 5.

Finally it must be stated that the writer was able to undertake this investigation as the recipient of the Dr. James Douglas Research Fellowship in Mining Engineering.

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INTRODUCTION

A study of the literature dealing with ball milling, a part Bibliography of which is given in the Appendix, leads to a first conclusion that considerable research has been undertaken on this subject. However, on closer study, it is apparent that a great deal of the work has been purely academic and of very little use to the practical mill operator. In the first place a large part of the literature is devoted to the development of mathematical theories of crushing and their approval or condemnation; in the second place much of the practical work performed in laboratories has been done with inadequate equipment, that is if the results are to be applied to actual milling practice. Small laboratory mills with batch charges cannot be expected to give conditions approaching those in a full size mill with continuous feed and discharge.

It must not be thought that the writer is condemning one and all of the investigators in this field; far from it. Some excellent work has been done and much useful information has resulted; but he does feel that only one systematic study has been made of ball milling in all its phases and along lines that will produce conclusions of value to the milling fraternity.

This has been done by Messrs. Gow, Guggenheim, Campbell, and Coghill whose paper has been published recently by The American Institute of Mining and Metallurgical Engineers as Technichal Publication No. 517, "Ball Milling".

The work was done under a cooperative agreement between the Mississippi Valley Experiment Station of the United States Bureau of Mines and the Missouri School of Mines and Metallurgy, Rolla, Missouri.

A thorough study of ball milling was made under favourable conditions, with investigations made in the plants of two large mining districts combined with the results from laboratory tests.

In the paper it is claimed that a 2 foot mill could be used to forecast the work of a commercial mill. This may be so, and, if true, establishes the 3 foot mill used at McGill University as a very desirable one for the same purpose. It supports the contention of the writer that anything smaller than a 2 foot mill is liable to give erroneous results.

In 1932, before this paper by Gow et al: was published, it was decided at McGill University to undertake a thorough investigation of ball milling in relation to all the variables.

The plant was erected in the summer of that year and work was started on the investigation which it is considered will take several years. As the work proceeds it will be interesting to see how the conclusions arrived at compare with those presented by other investigators, particulary the most recent.

A practical study of grinding in ball mills must be based on the grinding capacity and efficiency of the mill, and only useful grinding can be considered.

The basis that immediately suggests itself for such a study is one in which the operating variables are considered one by one in their effect on grinding. At first sight it would seem an easy matter to ascertain the effect of each variable in turn on grinding by maintaining all the others constant. However, on closer observation, this is found to be more difficult on account of the fact that some of the variables are induced.

This point is very well brought out in the paper on "Ball Milling" by Gow et al; referred to above, and the writer is so convinced of its bearing on the subject that a section from that paper is presented in full.

OPERATING VARIABLES IN GRINDING

"Grinding capacity and grinding efficiency are the ultimate values which interest the operator and which must be increased, either separately or together as the case may demand, so that ball milling may be improved. Capacity is expressed in surface tons per hour and efficiency in surface tons per net (or gross) horsepower-hour. In each case, only useful grinding is evaluated; the calculations are carried down to a limiting size beyond which additional grinding is unwarranted. The limiting or "useful" size will vary with different plant requirements, but in this investigation two sets of calculations have been used, those through 65-mesh and those through 200-mesh. Since the method of making these calculations has been discussed elsewhere, no further explanation is necessary here.

All the operating variables affect the capacity and efficiency of grinding, but for a thorough understanding of their effects they must be divided into two groups, set variables and induced variables. The set variables are those that are not changed by other operating conditions and include the size and design of the mill, the size of the discharge opening, the type of lifters, the speed of rotation, the amount and size of the ball charge and the type of feed. Also, the feed rate, the sizing analysis of the feed, and the pulp density generally may be considered in this class.

On the other hand, the induced variables are such factors as the amount of ore in the mill, the location of the center of mass of the ball-and-pulp charge, the amount of slippage, the power required and, in closed-circuit grinding, the type of the circulating load.

A variation in one of the set variables might tend to produce a certain change in the capacity or efficiency of a mill, but also it might result in changes in an induced variable, which would either magnify or diminish the primary tendency. Were it not for these induced variables, the investigation of ball milling would be a simple matter; the different set variables could be studied to find the conditions of best speed, of best mill volume of balls, of best circulating load, and so on. However, both plant practice and laboratory work have shown that such a test procedure is not comprehensive."

The writer subscribes to the opinions set forth in the above statement.

During the Session 1932-33 at McGill, efforts were concentrated in perfecting the mechanical equipment of the installation. It was found that many changes were necessary and that considerable attention had to be given to the establishing of complete control over the many variables.

Complete details of this work are given in Mr. O'Shaughnessy's thesis for that year.

Only three tests were run, based on the effect of the speed of rotation of the mill on the efficiency of grinding. No conclusive results were obtained, so it was decided that the same basis should be used for the tests in the Session 1933-34, which work this paper deals with.

It was found that many minor changes had to be made in the then present equipment, as well as several additions to the plant.

A list of the equipment follows:

(Detailed description will be given of that which was new during the period covered by this report; the other apparatus is fully described in Mr. O'Shaugnessy's work and is reproduced here in part.)

GRINDING PLANT AND EQUIPMENT

(1) Power equipment:-

(a) D. C. power line from the University Power Plant, at approximately 220 volts.

(b) A. Thompson integrating wattmeter (G.E.Co.) permitting direct reading to within 10 watts and estimating to 5 watts of the power consumption.

(c) A voltmeter and an ammeter for direct sight readings.

(d) A 7½ h.p. English Electric D.C. motor. This motor drives the ball mill through pulleys and a belt, the pulley on the ball mill being connected to the main gear on the mill by a pinion.

(e) Line voltage resistances for controlling the voltage delivered to the motor.

(f) Field resistance for controlling the speed of the motor.

(2) <u>Milling plant:-</u>

(a) A Marcy ball mill made by Mine & Smelter Supply Co., Denver, Colorado, with a feed scoop and quick discharge grid. The mill is mounted on trunnions.

(b) A Denver Classifier.

(c) Centrifugal pumps.

(d) An automatic pressure grease gun delivering grease to the main mill bearings.

(e) Three automatic pulp samplers, one for the mill discharge, one for the classifier return sands and one for the classifier overflow.

(f) Oil container continuously oiling the gear and pinion drive on the mill.

(g) Water supply from a constant level tank with adjustable feed valves.

(h) Overflow Control Tank. (Classifier)

(3) <u>Ore feeding equipment:-</u>

(a) A hopper for feeding the ore through a feed box onto

(b) An endless rubber belt conveyor delivering the ore into the mill.

(3) Continued

(c) A mixing machine for preparing the ore after crushing and screening so that a more or less uniform feed may be delivered to the mill.

(4) Mechanical equipment:-

(a) Electric revolution counters registering the forward travel of the feed-belt, the revolutions of the mill and the strokes of the classifier. A push-button tally is also provided.

(b) Mechanical speed counter, connected directly to the motor, for registering the revolutions of the motor.

(c) A Bell Brake - This is a mechanism consisting of brake band, lever arms and a balance and is used for the measurement of applied brake loads in ascertaining the power output from the motor.

(5) Miscellaneous equipment:-

(a) Vacuum pump and filters.

(b) Air compressor and lines.

(c) Graduated sampling beakers.

(d) Scales.

(e) Drying ovens.

(f) Buckets and Tubs.

(g) Bell Screening Machine with Tyler Standard screens.

DESCRIPTION OF PLANT AND EQUIPMENT

Power Control.

The power line in the laboratory comes from the University power house and is direct current usually delivered at 224 to 228 volts depending on the line load which fluctuates widely during the day. In order to be certain of the efficiency and speed of the motor it was found necessary to keep the applied voltage constant during the tests. To do this two variable resistances of .036 ohms each were inserted in series in the incoming line. They each have 24 taps. For light loads a further fixed resistance can be plugged in the circuit. With this arrangement it was possible at all times to keep the applied voltage at 220 volts. A sight voltmeter indicated the voltage and the controls were shifted manually.

Power measurement.

With the voltage constant sight-power readings could be obtained with the ammeter. During all tests power consumption was measured with a Thompson, integrating, D.C. wattmeter. The test needle on the meter was replaced by a larger dial which was graduated and thus facilitated reading the meter accurately. The wattmeter was examined and tested by the electrical department. It varied less than 1% of the true reading at the end of one hour's use. This correction was not made in any of our calculations as we are principally interested in motor output which we determined accurately.

Motor.

The motor was designed and built by the English Electric Company. It is compound, with a continuous rating of 30.6 amps, 220 volts at 625 r.p.m.

The speed is controlled by two variable resistances in series. The smaller resistance has 36 taps and the larger 21 taps, two taps on the larger having about the same effect as the total smaller resistance so that a very fine adjustment of speed is available. The resistances cut the field current from 1.5 to 0.2 amps with a corresponding speed range from 640 to over 2000 r.p.m. at light loads. The motor has a cooling fan attached to its shaft. This permits good cooling of the windings and the temperature of the machine under load becomes and remains constant after a short period.

The Bell Brake.

In order to determine the output of the motor for any input, the armature shaft was permanently connected through a flexible coupling to a Bell brake. The brake consists of the usual brake drum with a steel shaft mounted in ball bearings. The braking load is applied by winding or lapping a canvas belt, which has been soaked in oil, on the drum. One end of the belt is attached to a system of levers, the other passes around a portion of the brake drum, over a roller, which can be shifted to any position about the drum (hence lapping or unlapping the amount of belt on the wheel), and is attached to a lead weight hanging freely. The roller which controls the belt lap is operated through a worm gear so that very minute changes in load conditions can be made. In using the brake the tare of the belt and weight is obtained and this weight substracted from the weight recorded on the balance. The drum is cooled by a continuous stream of water, from a constant level tank, which is directed inside the drum. It flows to the edges, around the inside of the braking surface and is scooped out by a pipe, adjusted close to the inside periphery of the wheel, and run to waste. The advantages of this type of brake over others is its extreme sensitivity and smoothness in applying a load which can be kept constant for long periods.

Speed Reduction Drive.

The motor has a $5\frac{3}{4}$" paper pulley on the armature shaft. It drives a 4-ply endless rubber belt running on the 24 inch wooden mill pulley. This in turn drives the countershaft and pinion with 15 teeth and the main mill gear with 91 teeth. Both gear and pinion are kept lubricated with oil as the gear dips constantly into an oil reservoir. Both are protected from dirt and grit by a metal cover which also prevents oil from spraying about the laboratory when the mill is operating.

The belt is kept in uniform tension by a counterweighted idler pulley or belt tightener.

The pulleys on the motor and the mill are replaceable by ones of different diameters.

<u>Ball mill.</u> (See Photograph No. 11.)

The ball mill is three feet long and averages 24.04" in diameter inside the liners. The liners are of manganese steel, wave type, with 6 longitudinal waves. The height of the wave crest above the trough is 1.05". They are made in 6 pieces and are bolted to the mill shell. The feed scoop is of a standard type with a spiral conveyor through the main trunnion. The mill is equipped with a Marcy quick discharge grid. The weight of the mill is carried on the two main trunnions which are mounted in babbit journal bearings kept constantly lubricated by grease from an automatic grease feeder. The total weight of the assembled mill and liners is 3725 lbs. Facilities are arranged so that the mill can be lifted out of the bearings and lowered to the laboratory floor where the end of the mill can be removed for any necessary internal adjustments. The mill is equipped with a small man hole through which the ball load may be put in the mill.

The weight and location of the scoop feeder caused a fluctuation in the amount of power drawn by the mill during its revolution. The scoop was counterbalanced by attaching lead weights to the main gear. The power drawn by the counterbalanced mill was quite steady.

Continuous Grease Feeder. (See Photograph No. 5.)

The grease feeder for the main mill bearings consists of a large cylinder containing a piston, piston rod and the necessary packing. The piston rod is threaded and has a stop catch key which prevents it from rotating when in place. The rod passes through a threaded wheel driven by a worm gear. The worm gear is operated by a speed reducer which in turn is driven by a large pulley connected by a leather belt to a small pulley on the mill countershaft. The overall speed reduction of the feeding arrangement is 2000-1.

The cylinder is filled with grease by pulling back the piston to its extreme position, (removing the key mentioned above in order to do this), attaching a hose from a vacuum pump to a pipe on the side of the cylinder and drawing grease from a container by means of the suction. When the gun is filled, necessary piping is replaced and the mill started. The slowly revolving threaded wheel forces the rod and the piston forward displacing the grease which is forced through piping to the incoming side of the journal bearings. The cylinder when charged is 7" long and 4" in diameter. Such a charge at about 80% critical speed lasts 60 hours.

Discharge Screen.

The discharge end of the mill is fitted with a circular screen (8 mesh) to take out large pieces of rock from the discharge. These might interfere with the pump if left in the circuit. The screen is washed with a continuous spray of water from a constant level tank. The water has a dual purpose; it keeps the screen open and washes most of the fine particles of crushed rock off the oversize which is discharged by the screen.

Pump. (See Photograph No. 5.)

The mill discharge mixed with a regulated amount of water is pumped to the classifier by a standard $1\frac{1}{2}$" centrifugal pump.

Classifier. (See Photograph No. 1.)

The classifier is a recent development brought out by the Denver Equipment Co. It consists of a rotating drag in an inclined box. The drag is a half section of a low pitch spiral; and has a reciprocating motion. During the down stroke the spiral is clear of the sand and water but on the up stroke it helps move the sands up the incline. In effect, the operation is a combination of Dorr and Akins principles.

Feeder. (See Photographs Nos. 2 & 3.)

The conveyor feeder consists of an endless rubber belt driven by a friction roller arm which is raised and lowered by a cam operated by a speed reducer and a small motor. The speed of the belt is controlled by adjusting the amount of movement the cam imparts to the lever arm. This is measured by a vernier attached to the arm.

The belt is loaded from a small hopper with a fixed opening. Felt pads under which the belt passes at the edges keep a feed of uniform cross section and prevent losses. The spill-way is directed into the feed reservoir at the feed end of the mill.

Automatic Samplers. (See Photograph No. 5.)

The samplers used to check quantity and quality of pulp in the mill circuit were developed in the McGill laboratory. As originally designed they consisted of a discharge pipe sloping at an angle of 45^0 which was rotated by a motor through a worm gear drive. In the circular path which the discharge end of the pipe made a radial cutter was placed. The cutter opening was made 1/50 of the area of the discharge ring and the edges were made radial so that it was natural to expect 1/50 of the total discharge would be caught by the cutter. When the sampler was connected to a steady flow of water which could be varied it was found that the portion of the total water retained by the sampler varied from 1/36 to 1/44 depending on the flow of water.

A study of the elemental equation representing the mathematics of the system verified the fact that the portion should be 1/50 but it also indicated that in the sampler as arranged the time factor (during which the sample was procured) was a function of the flow of water and that this was disturbed due to the relative oscillation of the water in the discharge pipe. It was felt that if the distributor was made narrower and radial the time factor would then be practically independent of rate of flow. A radial distributor was made and the results then varied from 1/41 to 1/44. The variation was traced to a disturbed oscillating condition in the water coming out of the distributor. Two baffles were then inserted in the elbow at the entrance to the distributor and the sampler became quite steady. It did not reach the 1/50 expected but in all probability the difference is due to the thickness of brass about the cutter opening - diverting an extra amount of water through the opening.

Water Supply.

Water is added to the circuit by three pipes leading from a constant level tank, one to the mill, another to the head of the classifier and a third to the mill discharge. The ends of the pipes in the tank are screened over to keep out foreign matter. Calibrated valves allow the control of the water to within a few pounds an hour.

Air vents are taken out from the elbows in the pipes and by means of pet cocks the entrapped air may be removed from time to time.

Feed Hopper. (See Photograph No. 3.)

The rock is fed to a small, circular hopper from which it drops directly to a small box built over the conveyor belt. There is a clearance between the main hopper and the feed box so that the feed pressure on the belt is more or less independent of the amount of rock in the main hopper.

Recorders. (See Photograph No. 4.)

The motor is directly connected to a speed counter - a worm gear and graduated wheel operating a Crosby recorder. The classifier, mill and conveyor feeder have make and break contacts on them. The revolutions or strokes are recorded by magnetic recorders presented to the department. The counters require about 27 volts for steady operation. Four 28 volt lamps were connected in series, three being used to illuminate the recorders and the circuit being tapped off across the fourth, making a very satisfactory arrangement.

Feed Cover.

The feed scoop had a tendency to throw the feed about the laboratory at high speeds so it was enclosed with a metal cover.

Classifier Overflow Control Tank.

This is shown in Photograph No. 6

It was devised to overcome the effect on the automatic sampler of the uneven discharge from the mill and thence the overflow from the classifier; also to provide some measure of the state of balance of the circuit.

The pulp from the mill discharge is pumped to the intake of the classifier. The overflow from the latter goes to this Overflow Control Tank. It passes through a fine screen and then through a 6" cylindrical tank to a circular cone, the bottom of which leads into a 3/8" pipe, 9" long. To the bottom of this pipe is attached a gate valve with a fine screw adjustment, which allows the pulp to be kept at a more or less constant level in the upper tank.

After passing through the gate valve the pulp flows through the cutter of an automatic sampler. The upper tank is provided with an overflow as shown and with windows. The bottom of the conical tank is joined to the pipe column by a union joint. An air line enters this joint so that air may be blown in the bottom of the tank for agitation purposes.

A small pipe joins the pipe column near the bottom. To this is attached a water gauge so that the pulp level may be accurately measured.

Ore Mixer.

This machine was made in the laboratory and was designed to provide a mechanical mixer for the purpose of producing as near as possible a "perfect" mix so that the feed to the mill should be of a constant character.

The underlying principle of the machine is that of cutting and the kernel was made up from the mechanism of a spare revolving sampler, similar to those in use with the ball mill, the cutter being replaced by a feed spout of 1" pipe.

Photographs No. 8 & No. 9 show this machine, some details of which follow:

A circular box 12" in diameter was made out of brass sheet. Within this box was soldered a circular partition and the space between the outside wall and the partition was divided into ten equal compartments. An opening was allowed from each of these compartments and chutes 1" square were attached at an angle of 45° to carry the rock from the compartments to bags or boxes, as required, standing on a revolving wooden platform. An inlay was made in this platform to carry a scale as shown in the photographs.

The ore is fed from an elevated platform into a vertical pipe 1 ft. in diameter. At the bottom of this pipe an inverted cone was placed, set in a hopper. This was for the purpose of eleminating any classification of the rock. The hopper feeds directly into the mixer through a 1 1/8" pipe to a slot gate and thence by a 1" pipe to the spout of the mixer.

When in operation the vertical pipe and the hopper are kept full right up to the charging floor.

The flow of the ore is as follows:- through the vertical pipe onto the inverted cone, and into the hopper; thence, by opening the gate, it flows into the spout of the mixer which is being revolved by an electric motor; the spout delivers it into the ten compartments from whence it slides down the chutes into boxes or bags.

DISCUSSION OF CHANGES MADE IN PLANT AND EQUIPMENT

The experience during the previous year showed that considerable work had been necessary to prepare the plant for making tests.

Almost the entire year was spent in making additions and adjustments to the plant.

It was found necessary, during the year covered by this report, to make some further changes, details of which follow:-

Water Supply.

Some difficulty had been encountered in obtaining a satisfactory control and calibration of the water supply so it was decided to overhaul the whole system.

Previously two lines had been taken from the big constant level tank and a third from a smaller tank. All three now come from the big one. The iron pipes used were considered a source of dirt, causing blockages in the valves, so they were replaced by brass piping throughout. Further, the tank was thoroughly cleaned out and the intakes of the pipes for the water supply were screened over.

New slot valves were made with smaller slots than previously so that more accurate calibrations could be made.

The three valves were accurately calibrated, as was thought; but, after running several tests, it was found that the flows at the beginning and end of the tests were not the same. At first it was thought that particles of foreign matter were causing the difference; however, a check-up of the system did not correct this condition. So it was decided that the cause was entrapped air. To eliminate this the upper elbows in all three pipe lines were tapped by means of small brass tubes leading to pet cocks. As the air accumulated in the upper elbows the pet cocks could be opened for a short time and the air drawn off.

In the later tests it was found that this had solved the problem fairly satisfactorily. The beginning and end flows rarely varied to any great extent.

It is considered that the water supply system, as it exists to-day, is in a condition that allows of satisfactory control.

REVOLUTION COUNTERS

Some slight alterations were made in the make and break contacts of the electrical recorders for the ore conveyor and the ball mill.

All these contacts are now single action, being operated by a cam making one contact as follows:-

(a) for each upward movement of the friction roller arm operating the belt conveyor.

(b) for each revolution of the mill.

(c) for each forward raking movement of the classifier rake.

Ore Feed Hopper.

Originally the hopper was pyramid-shaped. It was found that this caused considerable classification of the rock, the fines tending to accumulate in the corners. This condition was aggravated by the hopper being fairly large. Therefore, the hopper was replaced by another one much smaller and conical in shape. This improved matters considerably, and was helped by the addition of only from 30 to 40 pounds of ore at a time.

Mill Discharge End.

In the early tests it was found that considerable "gulping" took place in the discharge of the pulp from the mill. In trying to improve this condition it was discovered that the lifters on the quick-discharge end of the mill were not throwing the pulp out as they should into the discharge trunnion. Instead of falling into this trunnion, a good deal of the pulp was running round the edge of the lifters and back into the well on the outside of the grid.

In order to correct this, an extension was built onto the centre of the lifter section so that the pulp dropped well out into the discharge trunnion. While this did not solve the problem of the uneveness of the discharge, it is probable that it helped somewhat to do so and it at least eliminated one of the possible causes. Further, with the added extension, it was found possible to thrust a pan under the lip and thus obtain a fairly representative sample of the moisture content within the mill.

It would seem that there is some fault in the design of the lifters on the Marcy ball mill, because, even with the extension that was added, there was a considerable run-back of pulp into the discharge well of the mill.

Classifier Overflow Control Tank.

As has been mentioned before, the flow of pulp from the mill was very uneven. This uneveness was transmitted to the overflow from the classifier and gave erroneous results from the automatic sampler. One gulp too few or too many in any given time caused a considerable difference in the readings on the graduated flasks in which the cut samples were collected.

In order to overcome this difficulty it was decided to allow the overflow to feed into some sort of a settling tank, the flow from which could be controlled. First of all a small cone,- 9" long, 6" diameter at the top and $1\frac{1}{4}$" diameter at the bottom,- was tried. It was found to be too short for suitable control. The length of pipe between the bottom of this tank and the sampler was then increased, but it was still found unsatisfactory. Finally a cylindrical tank a foot in length was superimposed on top of the conical tank and this combination was found to be better.

Refinements were added which enabled a very good control to be obtained. These included a screen at the top of the cylindrical tank; an air line for agitation at the bottom of the conical tank; and a water gauge attachment fixed to a graduated scale which served as an excellent indicator of the pulp level.

As has been described elsewhere, the slot valve was controlled by a sensitive screw adjustment, allowing very small changes to be made.

This apparatus is considered a very important addition to the plant. With careful attention, an even flow to the sampler can be maintained. Further, the water gauge supplies immediate evidence of any change in the discharge rate from the mill and was found very useful to indicate when the circuit had reached a state of balance.

It may be that some further improvements will be made in this equipment, but there is no doubt that it has proved of great value.

Ore Mixer.

In preparing the rock for the tests it was crushed, screened and bagged. It was thought that this would provide a fairly uniform feed. However, the first five tests showed that this was not so as evidenced by the variations in time taken for similar amounts of feed to pass through the hopper of the ore feeder. For example, in Test No. 5, variations in the feed rate for individual boxes, all of which were the same weight, were as much as seven pounds per hour on each side of the average feed rate.

At the conclusion of this test the mechanism of the feeder was thoroughly checked and tested, but still gave wide variations. Therefore, it was decided to study the effect of mixing the feed. 1,280 pounds of feed were cut in thirty two parts by hand on the riffles and used in Test No. 6. An immediate improvement was seen, variations in feed rate from the different boxes being much slighter. Instead of extreme differences of seven pounds on each side of the average feed rate, as in Test No. 5, these were only two pounds now.

This brought about the decision to make a mechanical mixer that would cut down on the time and labour involved in mixing by hand, and Professor Bell designed a machine which was subsequently built in the laboratory. The essentials of this machine are described elsewhere.

On completion of the mixer, it was decided to determine how many passes through the machine were necessary to ensure good mixing.

Before starting, four bags of the crushed and screened product were taken at random and sampled. Screen analyses showed very uneven mixing, especially on the coarse sizes, as had been expected from the uneveness shown in the rate of feeding by the ore feeder.

Then the crushed and screened rock was all passed through the mixer once in lots of 500 lbs, producing 20 such lots. One bag from each lot was cut down to provide samples for screen analysis, it being assumed that the bags in each lot would not vary appreciably. Each bag from which a sample was cut was weighed. The products on each screen were multiplied by the weight of the corresponding bag and the totals of this result for twenty bags of each size were divided by the total weight of the original twenty bags to arrive at a "perfect" mix for five tons of rock. This "perfect" mix was to be aimed at and the rock was to be passed through the mixer until this end was attained.

Therefore, one lot of twenty bags, that is one bag from each of the twenty 500 lb lots from the first pass through the machine, was put through a second time, being taken out in boxes of approximately 33 lbs. in three lots of ten. Two boxes from each ten were sampled and screen analyses made.

It was found that the two samples from the same lot checked fairly well, but varied considerably from those of the other two lots. The average of the six samples checked with the "perfect" mix on the fine screens from 14 down, but varied as much as 4% on the coarser sizes.

The same 1000 lbs. were put through a third, fourth, fifth and sixth time, but only one box out of each ten boxes was sampled, it having been demonstrated on the second cut that the boxes in any one lot closely resembled one another in mixture.

On each successive cut it was noted that a closer approach to the "perfect" mix was made, the finer products checking very well. But plus 4, plus 6 and plus 8 products continued to show considerable variations.

It is impossible to say how many passes would be necessary to even out these variations, but it was decided that five or six would be sufficient for the purpose of these tests, especially as the fines, which affect the mechanical value of the feed, did seem to be well mixed.

<u>Summary</u>.

This concludes the description of plant and equipment and the discussion of additions and adjustments made during the Session 1933-34.

The two most important additions to the plant are the Ore Mixer and the Classifier Overflow Control Tank.

It is considered that this new equipment should prove of great assistance in the continuation of the research, and that the other improvements have resulted in a plant more suitable for the study of fine grinding.

METHOD OF DETERMINING RELATIVE MECHANICAL EFFICIENCIES

A great deal of the work done in the field of crushing and grinding has been devoted to the finding of a method for determining the efficiency of crushing.

No suitable means has been discovered due to the inability to measure the work usefully done.

Therefore attention has been focussed on the measurement of efficiency by means of relative mechanical efficiencies. This gives an indication of the useful work done by measuring the reduction in size of particles during the crushing operation in units representing energy values.

The Kick versus Rittinger Controversy.

Two main theories of crushing have been advanced for the expression of relative mechanical efficiencies, namely the Kick and the Rittinger.

These theories may be stated thus:-

Kick:- "The energy required for producing analogous changes of configuration of geometrically similar bodies of equal technological state varies as the volumes or weights of these bodies."

Rittinger:- "The work done in crushing is proportional to the surface exposed by the operation."

In the research work being done at McGill University it has been decided to use the Rittinger theory, and it may be interesting to follow the steps which led to this decision.

From the literature on the subject the following points are of interest:-

1. In 1906 Messrs. Pearce and Caldecott proposed the representation of the efficiency factor by the reciprocals of the diameters of the particles.

2. In the same year Messrs. Klund and Taylor suggested that the efficiency factor should be represented by the squares of the diameters of the particles.

3. In 1909 Chapman suggested as the efficiency factor the number of mesh per linear inch of any set of screens with a constant ratio between diameter of wire and mesh aperture.

These three proposals are all based on Rittinger's theory.

4. In 1910, Stadler wrote his paper on "Grading Analyses and Their Application." He claimed that the only accurate method of determining the energy absorbed would be one based on Kick's Law, the essence of which is that "the energy absorbed in crushing is proportional to the reduction in volume."

This paper constituted the first serious attack against Rittinger's theory.

It was shown theoretically that Rittinger's theory required the use of about 25 times as much power, as that required by Stadler's enunciation of Kick's theory, to reduce 1" rock to 200 mesh.

It should be noted that all the discussion to date had been purely theoretical, and it was obvious that practical work would have to be done to decide the point.

Other theoretical papers have been presented from time to time, notably by del Mar, Speak and Taggart, but the experimental work has been the proving ground of the two theories.

5. In 1912, H. Standish Ball wrote a paper on "The Economics of Tube Milling" based on experimental work at McGill University. It was claimed that Kick's Law had been substantiated but Professor Bell of McGill later showed that there had been an error in the reasoning.

6. The next work of importance was by A. O. Gates whose paper "Kick vs. Rittinger: An Experimental Investigation in Rock Crushing Performed at Purdue University," was published in 1915. He performed experiments with a testing machine and arrived at the conclusion that Rittinger's Theory more nearly represented the actual facts than any other proposed hitherto.

7. Further substantiation for Rittinger was brought forward by John W. Bell at McGill University in the succeeding year. Extensive tests using rolls and crushers produced results similar to those of Gates.

8. Finally in 1928 Gross and Zimmerley lent further support to the Rittinger theory; and in the recent publication by Gow, Guggenheim, Campbell and Coghill on "Ball Milling" this theory was accepted without discussion.

Summing up the situation, it is evident that there are strong theoretical supporters of the Kick theory; but it is no less evident that Rittinger is substantiated by the bulk of the practical work.

For this reason Rittinger is the theory accepted by McGill University and it is the opinion of the writer that it is the one accepted by most interested people to-day.

However, before leaving this subject, some mention should be made of another method that is used, especially by mill operators, in determining the efficiency of crushing of machines. This is known as the "Tons crushed per horsepower-hour" method. Determination is required of the tonnage, power consumed and screen analysis of the finished product. If it is only required that the final product shall all pass a given limiting screen, then this method is satisfactory. However its use is usually limited by the fact that the amounts of the product in the different sizes below the limiting size must be considered.

It is interesting to note that this method has been adopted by Gow, Guggenheim, Campbell and Coghill in their recent paper on "Ball Milling." Since the writer regards this paper as an outstanding contribution to the research on milling, he would like to suggest that serious thought be given at McGill University to making a trial of the "Tons crushed per Horsepower-hour" method at some future period in the present investigation.

DESCRIPTION OF TESTS

Introduction.

The basis of the work has been to determine the effect of variation in the speed of rotation of the ball mill on the efficiency of grinding.

Eighteen tests in all have been made at speeds ranging from 28.5 R.P.M. to 52 R.P.M. or approximately 50 % to 92 % of critical speed.

Results have shown that increase in the speed of rotation of the mill above a certain point leads to less efficient grinding.

It had been hoped to run some tests at speeds above the critical speed, but this unfortunately was not possible.

Many important adjustments have been made to the plant as well as several additions of new equipment.

Preliminary Work.

(1)Remodelling of Water System.

It had been found during the previous year that the water system was unsatisfactory and unreliable. Therefore, the first work undertaken this year was to overhaul the system completely replacing the iron piping with brass and making other adjustments, fully described elsewhere.

(2)Calibration of Equipment.

(a) Having changed the water system it was then necessary to calibrate the three cocks. Considerable time was spent in doing this and it was considered that the cocks could be set within a pound or two of any required flow.

Subsequently it turned out that these calibrations were very inaccurate due to the presence of entrapped air. This was rectified by drawing off the air through pet cocks.

Re-calibration was made only over the ranges to be used in the remaining tests, so it still remains for a full calibration to be made.

(b) Some adjustment had been made in the ore feeding equipment so that a calibration of this was necessary. This was done over a wide range of settings on the vernier. However, once again, this calibration was found to be unreliable, the cause eventually being traced, after considerable experimentation with the friction roller, to the uneven mixture of the feed.

A second calibration was not undertaken as it was found that the original one gave fairly close approximations which could very quickly be adjusted after the tests had been running for a short time.

(3) Screen analyses were made from several samples, taken at random from the prepared feed, to determine the mechanical value of the feed. The rock used in these tests was a pure quartzite, absolutely homogeneous and very desirable for an investigation on grinding. It had been prepared by crushing and screening to remove the fines.

Supplementary Work.

After the preliminary work described above the series of tests was commenced. However, from time to time, it was found necessary to make changes or do other work than that which was routine for the carrying out of the tests, some details of which follow.

(1) After running four tests it was evident that the discharge from the mill was very uneven. This was shown by the irregularity in the classifier overflow samples after sufficient time had elapsed to allow a balance to be reached in the circuit. It was decided necessary to arrange for some control of the pulp between the overflow end of the classifier and the sampler. Considerable time and study was devoted to this end, various ideas being tried, and eventually the overflow control tank was developed.

This was improved upon on several occasions and ultimately resulted in a very useful piece of equipment. It not only counteracted the "gulping" effect, but also served as an indicator of the point when a balance had been arrived at in the circuit.

(2) The uneveness of the mill discharge also led to an investigation of the mill discharge end. It was found that the lifters were not performing their work properly, in that the pulp was not being thrown out into the discharge trunnion in an even stream, some of it running back into the well outside the grid. In order to correct this the mill was taken down and an extension was built on to the lifters to correct this fault.

It might be mentioned here that the inside of the mill was examined at this time and found to be in perfect condition. Also the balls were weighed and the broken ones discarded.

(3) Automatic Ore Mixer.

As has been described elsewhere, this machine was built in order to provide a more uniformly mixed feed to the mill than had been possible formerly. This condition was particularly desirable so that the feed rates should be approximately constant.

After the mixer had been made a fairly extensive study was made of its performance, details of which are given under "Discussion of Changes Made in Plant and Equipment."

General Method of Procedure in Making Actual Tests.

The method of operation in all the tests was not exactly the same. However, gradually a definite scheme of operation has been developed and Tests 12 to 17 were all on this basis.

A summary of the main steps in this procedure follows:-

(a) It having been decided under what conditions a test was to be run, the amount of water desired from each cock was calculated and the cocks set at the points to give the required flows. Then these flows were checked by actual measurement so that there could be no doubt about them.

(b) The vernier setting on the friction roller arm operating the feed belt was adjusted to provide the feed rate desired.

(c) The ball mill was started up with its rheostat set on the tap to provide the required speed of rotation.

(d) The ore feeder was started up.

(e) The water cocks were opened.

(f) As soon as the mill began to discharge pulp the pump carrying the pulp to the classifier and the classifier rakes were set in motion.

(g) The voltage in the line to the motor was kept at a constant figure by a resistance control.

(h) As the classifier began to build up, the overflow control tank was periodically adjusted to give an even discharge. When the circuit was in balance it was found that these adjustments were necessary only very occasionally.

(i) After the mill had been running for about two hours, when it was considered the circuit was approaching a balance, readings were commenced at the control board and preliminary samples of the classifier overflow were taken.

The readings at the control board were as follows:-

Voltage

Amperes

Wattmeter readings giving input K W hrs.

Motor R.P.M.

Mill R.P.M.

Classifier Rakes/minute

Ore feeder Strokes/minute.

(j) When the preliminary samples showed that the mill was in balance, final sampling was commenced.

(1) Classifier Overflow.

The automatic sampler was set in motion and samples for a measured time were collected in large graduate flasks. At the same time the flow that was not collected by the sampler was caught in big tubs which could be weighed and later dried. These tub samples served as a check on those given by the sampler.

As these overflow samples were taken they were weighed and calculations were made to show the amount of pulp in the overflow.

Sampling was continued until it was apparent that a balance had been reached in the circuit or would never be reached due to some undesirable condition.

(2) Mill Discharge and Return Sands.

Automatic samplers were also used for these two products.

The samples were collected in buckets and were taken to correspond with the overflow samples.

(3) Oversize.

The oversize from the mill discharge was collected in buckets and the amount per hour at different stages of the test calculated.

(4) Moisture Sample.

A pan was thrust into the discharge end of the mill and held under the discharge flow from the lifters. It was found that this gave a very fair approximation of the moisture content in the mill.

(k) Rate of Feeding Ore.

The rock was taken out of the mixer in lots of approximately 33 pounds. Exact determinations of weight were made and the boxes stacked on the feeding floor.

One box at a time was poured into the hopper and the exact time taken for the feed to pass through the hopper was noted. This provided the necessary information for calculation of the feed rate.

(e) When the results desired had been obtained, the plant was shut down and the mill and classifier washed out. Then the water supply was remeasured to see if it varied from that at the beginning of the test.

Subsequent Operations.

The samples that were of importance were filtered and dried. The overflow, mill discharge and return sand samples were prepared for screening and then screen analyses were made. These results provided data for calculation purposes.

RESULTS AND CALCULATIONS

Forms for Results.

Two forms were drawn up to enable the more important data to be recorded and presented concisely. The first of these two forms is for general data, the second for calculations necessary for determining relative mechanical efficiencies.

Some details follow, considering the first form first.

Crushing Media.

At the beginning of the work undertaken it was considered that the mill would still contain approximately the 1200 lbs. of balls added in the previous year and made up thus:-

$1\frac{3}{4}$ inch balls............616 lbs.

$1\frac{1}{2}$ inch balls............584 lbs.

On the conclusion of Test No. 6, when the mill was taken down to make adjustments to the lifters, all the balls were removed, cleaned and weighed.

The weights were as follows:-

$1\frac{3}{4}$ inch balls............578 lbs.

$1\frac{1}{2}$ inch balls............587 lbs.

Broken balls............. 10 lbs.

1175

Whether there was some error in the weighing in the previous year or whether 25 pounds of balls were used in grinding is not known.

The broken balls were discarded and the others recharged into the mill and used for all subsequent tests.

Mill Pulp.

The percentage of moisture decided upon for the mill was provided by the water in the return sands plus the water from Cock No. 1, added direct to the mill.

In the later experiments a check on this was provided by the taking of moisture samples, as described elsewhere.

Mill.

(1) Speed. The revolutions per minute for the ball mill were given by the electrical recorder. An average was taken for the readings during the time that it was considered the circuit was in balance. The critical speed has been taken from Mr. O'Shaugnessy's thesis.

(2) Oversize. The oversize that would not pass through the 8 mesh trommel on the discharge end of the mill was collected in a bucket, dried and weighed.

Belt Feeder.

(1) Vernier Setting. This was the setting on the adjustment of the friction roller arm operating the belt feeder, the adjustment changing the feed rate.

(2) The feed rate was calculated from the results obtained by the timing of ore added to the feed hopper.

(3) The strokes per minute were given by one of the electrical recorders.

Time.

After starting up the mill for any one test, some time, represented by the preparatory period, had to be allowed for balance to be set up in the circuit. This point was indicated by preparatory samples and also in some measure by the gauge on the Classifier Control

Tank, and, once it had been attained, the sampling period was commenced.

Classifier.

The strokes were given by an electrical recorder.

The return sands were calculated from the results of screen analysis, as shown elsewhere. The water is not given as it was not measured.

The Overflow figures are obtained from samples collected in graduates and from tubs collecting the whole flow. Details are given elsewhere.

Water.

Calibration having been made of all the cocks before starting any tests, it was considered that the water could be controlled within a few pounds. Discrepancies in the first few tests caused an investigation which showed that the flow was less at the end than at the beginning of a test.

The cause was ultimately attributed to entrapped air and corrected. However, for safety, flows were measured before and after each test, except where one test followed immediately after another.

Power.

Sight power readings were taken from the voltmeter, ammeter, and wattmeter, and the input horse power calculated.

The motor efficiency was given by the brake tests, and the power delivered to the mill calculated.

The power lost in various ways was taken from Plate Number 5 in Mr. O'Shaugnessy's thesis,-Dead-Load Loss vs. Speed-for a ball load of 1165 pounds. An estimate of this loss was made for tests with a mill speed of less than 30 R.P.M., as the above mentioned curve did not go below that speed.

Further details of power calculations are given elsewhere.

The second form gives the determination of relative mechanical efficiency.

Screen analyses are given of the Mill Feed, the Mill Discharge, the Classifier Overflow, and the Return Sands.

Mechanical values are calculated for the Mill Feed and the Classifier Overflow, based on Rittinger's theory.

The further calculations are self-evident giving final figures for "Crushing Work per Horse Power," based on gross and net power to the mill.

Determination of Brake Horse Powers and Calculation of Motor Efficiencies.

A departure from the method of the previous year was made in carrying out the brake tests. Brake tests had been run previously over a range of motor speeds from 650 R.P.M. to 1550 R.P.M. and curves had been plotted. After the tests were run readings of brake horse power were taken from these curves.

It was decided that it would be more satisfactory to do away with these curves and to make brake tests under the exact conditions for each test. These were run on the completion of the series of eighteen mill tests, and the procedure was as follows:-

A summary was made of the details from each test necessary for making the brake tests, as shown on the accompanying sheet.

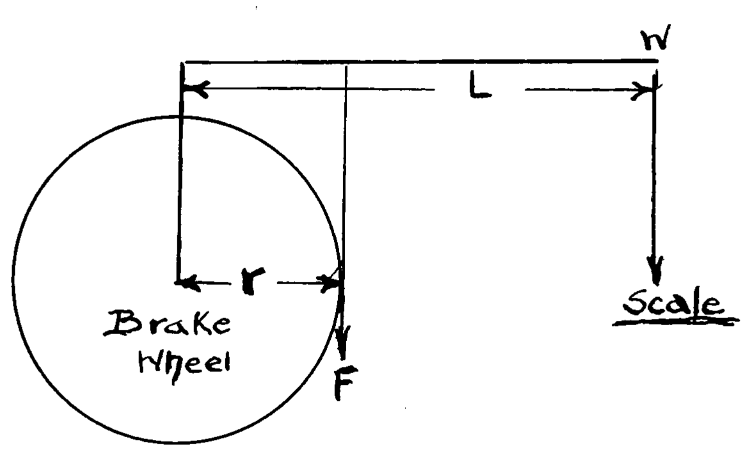
The belt between the motor and the mill was removed. Then the conditions for each test in turn were duplicated. First the motor starter was set on the right tap settings; then the load was applied with the brake until the volt and ampere readings were those required, the arm of the scale being in balance.Under these conditions the motor was allowed to run for several hours so that it could reach an even temperature.

Finally, readings of the wattmeter were taken and small adjustments made in the applied load until the required condition of Input KW hrs. was arrived at. This having been established, the gross weight shown on the scale was recorded.

The tare of the brake band had been previously determined, so that the net weight could be calculated.

A tabulation is given showing the results of the brake tests and the calculation of motor efficiencies.

In this connection the following formula was made use of, based on the mechanics of the brake.



$Fr = WL$ where W= net weight

$F = \frac{WL}{r}$

Work= $2\pi NWL$

where N= the R.P.M. of the motor

L= 2

$\therefore$ Brake H.P.= 0.000381 WN.

The cooling water resistance horse power was obtained from Plate II in Mr. O'Shaugnessy's thesis.

The efficiency of the motor was arrived at thus:-

$$\text{Efficiency} = \frac{\text{Total Output}}{\text{Measured Input}} \times 100.$$

SUMMARY OF DETAILS NECESSARY FOR MAKING BRAKE TESTS

Test No.	Tap Settings of Motor Starter	Amps	Volts	Input KW hrs.	Ball Mill R.P.M.	Motor R.P.M.
1.	0&0	15.0	220	3.48	28.50	676.3
2.	0&0	16.0	220	3.70	28.35	673.4
3.	0&0	14.5	220	3.33	28.42	674.9
4.	0&0	14.8	220	3.41	28.41	674.9
5.	0&0	14.3	220	3.27	28.47	675.6
6.	0&0	14.0	220	3.23	28.48	676.4
7.	9&0	Test of No Value. -Change in Voltage				
8.	9&0	19.0	214	4.18	39.33	932.2
9.	9&0	19.0	214	4.16	39.08	926.8
10.	9&0	19.0	214	4.23	39.07	926.0
11.	9&0	19.5	214	4.24	39.02	925.5
11A.	9&0	19.25	214	4.22	39.12	927.6
12.	0&15	13.75	214	3.01	28.45	674.5
13.	9&0	19.0	214	4.15	39.47	936.9
		Pulleys changed for higher speeds				
14.	0&40	20.25	214	4.47	44.07	726.8
15.	5&15	21.75	214	4.76	47.52	782.9
16.	7&20	23.75	214	5.21	52.00	856.4
17.	7&20	23.25	214	5.16	51.93	855.7

DETERMINATION OF BRAKE HORSE POWERS AND CALCULATION OF MOTOR EFFICIENCIES.

Test No.		1	2	3	4	5	6	7
Gross Wt.	lbs	25.10	26.00	24.60	24.80	24.30	24.00	
Tare	lbs	11.50	11.50	11.50	11.50	11.50	11.50	Test
Net Wt.(W)	lbs	13.60	14.50	13.10	13.30	12.80	12.50	
Speed (N)	RPM	676.	673.	675.	675.	676.	672.	of
Brake HP	HP	3.50	3.72	3.37	3.42	3.30	3.20	
Water Resistance	HP	0.02	0.02	0.02	0.02	0.02	0.02	No
Total Output	HP	3.52	3.74	3.39	3.46	3.32	3.22	
Measured Input	HP	4.67	4.96	4.47	4.57	4.38	4.28	
Effy: of Motor	%	75.3	75.4	75.8	75.7	75.8	75.2	Value

Test No.		8& 13	9	10,11&11A	12	14	15	16&17
Gross Wt.	lbs	22.75	22.75	23.00	23.00	28.50	28.37	28.12
Tare	lbs	11.50	11.50	11.50	11.50	11.50	11.50	11.50
Net Wt.(W)	lbs	11.25	11.25	11.50	11.50	17.00	16.87	16.62
Speed (N)	RPM	934	927	926	675	730	776	856
Brake HP	HP	4.00	3.97	4.06	2.96	4.72	4.99	5.42
Water Resistance	HP	0.08	0.08	0.08	0.02	0.03	0.04	0.06
Total Output	HP	4.08	4.05	4.11	2.98	4.75	5.03	5.48
Measured Input	HP	5.62	5.62	5.62	4.03	5.95	6.35	6.95
Effy: of Motor	%	72.6	72.1	73.1	74.1	79.8	79.2	78.8

RESULTS AND CALCULATIONS CONTINUED

Checks on Results of Tests Based on the Screen Analyses.

If the circuit is in balance, the amount of return sands will be equal to the amount of the mill discharge less the amount of classifier overflow. How about oversize?

Taggart, in his "Ore Dressing Handbook", gives the following formula for determining tonnages in a grinding circuit, if the screen analyses of the various products are known:-

$$T = Fc - C = \frac{Fa \quad (c-t)}{fc - t} - Fa$$

a simpler formula is

$$= C \, \frac{c - fc}{fc - t}$$

where

T - Amount of return sands.

t - % some one mesh product in return sands.

Fc.- Amount of mill discharge.

fc - % similar mesh product in mill discharge

C - Amount of classifier overflow.

c - %similar mesh product in classifier overflow.

Fa - Amount of feed.

This formula is based on theoretical calculations and is absolute providing the circuit is in balance and the screen analyses correct.

It has been used as a check on the state of balance of the various tests, as shown in the calculations in the Appendix.

These calculations were based on the distribution of the -200 mesh product, as it was considered that this would give the most reliable results. Figures are also given for plus 200, plus 150 and plus 100 mesh products.

If there is a complete balance the results would check for any given screen size, so that these figures give an indication as to whether this balance had been established. Further they provide results for the amount of return sands in the circuit, which amount was not determined in any other way.

Comparison of Finished Product and the Feed.

This table shows how the total finished product is arrived at by adding the amounts of the mill discharge and the sand return samples to that of the classifier overflow sample.

The total arrived at in this way is compared with the original feed less the amount of oversize. If the circuit was in balance, these should be the same.

If they were approximately the same it was considered that a state of balance had been reached, the results being within the limits of accuracy of the equipment.

Summary of Main Results of Tests.

In this table a summary of the more important results is given, from which the main conclusions have been drawn.

TOTAL FINISHED PRODUCT AND ITS COMPARISON

WITH THE AMOUNT OF FEED TO THE MILL

(Results in lbs/hr.)

Test No.		Classifier Overflow Sample	Mill Discharge Sample	Sand Return Sample	Total Finished Product	Feed less Oversize
1.	Solids	220	3	1	224	222
	Water	686	7	3	696	687
2.	Solids	314	4	5	328	308
	Water	1001	7	4	1012	1026
3.	Solids	294	4	3	301	295
	Water	574	7	4	585	676
4.	Solids	217	3	-	220	220
	Water	429	6	3	438	440
5.	Solids	189	4	-	193	196
	Water	373	7	2	382	372
6.	Solids	184	4	-	188	195
	Water	352	7	3	362	372
7.	Solids	Results	of	No	Value	
	Water					
8.	Solids	152	4	-	156	153
	Water	290	7	2	299	299

TOTAL FINISHED PRODUCT AND ITS COMPARISON WITH THE AMOUNT OF FEED

TO THE MILL..............CONTINUED

A sample

Test No.		Classifier Overflow Sample	Mill Discharge Sample	Sand Return Sample	Total Finished Product	Feed less Oversize
9.	Solids	164	4	-	168	166
	Water	332	8	3	343	343
10.	Solids	173	4	-	177	174
	Water	353	8	3	364	361
11.	Solids	158	4	-	162	161
	Water	308	7	2	317	317
11A.	Solids	151	4	-	155	151
	Water	311	7	2	320	317
12.	Solids	102	3	-	105	104
	Water	219	5	2	226	220
13.	Solids	146	4	-	150	153
	Water	304	7	1	312	316
14.	Solids	155	4	-	159	158
	Water	306	7	2	315	316
15.	Solids	151	4	-	155	156
	Water	302	7	2	311	313
16.	Solids	150	4	-	154	157
	Water	308	7	3	318	317
17.	Solids	128	2	-	130	129
	Water	277	3	2	282	287

SUMMARY OF MAIN RESULTS OF TESTS

Test No.	Mill R.P.M.	% Critical Speed	Feed lbs/hr.	Classifier Overflow lbs/hr.	Classifier Overflow -200 %	Crushing Work per H.P. Total Power to Mill	Crushing Work per H.P. Crushing Power only
1.	28.5	50.3	221	224	66.7	748	918
2.	28.4	50.2	308	323	58.6	886	1060
3.	28.4	50.2	295	301	53.5	861	1065
4.	28.4	50.2	220	220	64.0	726	894
5.	28.5	50.3	196	193	64.7	679	844
6.	28.5	50.3	195	188	69.7	734	916
7.		Results	of	No	Value		
8.	39.3	69.3	153	156	80.7	522	688
9.	39.1	68.9	166	168	77.0	548	723
10.	39.1	68.9	174	177	77.8	563	736
11.	39.0	68.7	161	162	80.7	535	698
11A.	39.1	68.9	151	155	85.5	509	665
12.	28.5	50.3	104	105	85.5	505	645
13.	39.5	69.6	153	150	82.0	531	702
14.	44.1	77.8	158	159	82.4	465	604
15.	47.5	83.8	156	155	84.3	443	579
16.	52.0	91.8	157	154	83.1	405	524
17.	51.9	91.7	129	130	87.1	352	456

DISCUSSION OF RESULTS

In performing these tests with a Marcy Ball Mill fitted with a quick-discharge grate it was considered that the most suitable mill had been chosen for the investigation to be undertaken. The results obtained, however show that difficulty was encountered in getting any capacity from the mill.

At a speed of 39 R.P.M. the capacity is approximately 160 pounds per hour, which is much lower than was expected. In fact, in all the tests, it was shown that the mill could be very easily overloaded.

In this connection, it is suggested that, at some future period in this investigation, the mill should be changed to an open end one, a feature possible with the mill in use, and a comparison in capacity made.

The main problem for investigation was the effect on the efficiency of grinding of variations in the speed of rotation of the mill.

Seventeen tests have been run on this basis.

A consideration of the results, summarised in the tables under the following headings:-

(1) Total Finished Product and its Comparison with the Amount of Feed to the Mill.

(2) Summary of Main Results of Tests.

has led to the following main conclusions:-

(a) Test Nos. 1 to 6 were more or less preparatory tests which led to the development of the Classifier Overflow Control Tank and the Ore Mixer. These additions to the plant caused the subsequent tests to be very satisfactory.

It might appear from the results for the first six tests that a satisfactory balance had been reached. It was apparently so in Tests Nos. 1 and 4; but the discharge rate from the mill in all these tests was so uneven that no great faith can be placed in the results.

(b) Investigations have been made over a range of speeds, from 50% to 92% of critical speed.

(c) There was considerable variation in the feed rates in the early tests; but several of the later tests were run at approximately the same feed rate.

(d) The amount of -200 mesh product at the lowest speeds was very small, increasing fairly steadily as the speed was increased. This is important in a consideration of the Relative Mechanical Efficiencies.

(e) Crushing Work per H.P.

This result forms the crux of the present investigation. Considering the crushing work done per useful horse power, it would appear that the lowest speed of all gave the most efficient crushing. This is very much open to doubt. Even if it is correct, the low amount of-200 mesh product at this low speed does not make it a desirable speed at which to operate.

Considering the more reliable tests it appears that the speed of 39 R.P.M. is the most reliable one. At that speed approximately 80% of the finished product is -200 and the crushing work per H.P. is about 700 surface units. This confirms the opinion of the manufacturers of the mill, who claim that 40 R.P.M. is the best operating speed.

Variations in the feed rate make comparison difficult, the high feed rates in the early tests accounting to a great extent for the large amounts of crushing work done per H.P. This is further illustrated by the correspondingly low figures in Test 12.

However, it is very evident that an increase in the speed of rotation of the mill causes a decrease in the relative mechanical efficiency.

In order to appreciate this point more fully the results of Tests 8, 9, 11, 11A, 13, 14, 15 and 16 should be considered, these all being at approximately the same feed rate.

Test No.	Mill R.P.M.	Crushing work per useful H.P.
8, 9, 11, 11A, & 13	39	695 (av)
14,	44	604
15,	47.5	579
16,	52	524

This clearly substantiates the conclusion drawn above.

It was intended to continue these tests above the critical speed, in order to investigate the theory propounded by Fahrenwald that a ball mill is more efficient at speeds above the critical speed, a second peak of efficiency being reached at about 140% critical speed.

Unfortunately this was not possible. However, it is considered that this part of the investigation, being carried out at McGill University is incomplete until some tests are run at these higher speeds.

SUGGESTIONS FOR FURTHER WORK

Considerable progress has been made in the investigation of fine grinding.

Interesting results have been obtained in the work covered by this paper.

However, the writer considers that the investigation of the effect of changes in the mill speed as a variable in grinding has not been completed.

It is suggested that some further tests be run at the low speed of 28.5 R.P.M., as none have yet been carried out since the classifier overflow tank has been added to the plant.

Further it will be necessary to make some study of conditions at mill speeds above the critical speed, as suggested above.

SUMMARY

A study has been made of the effect of a variation in mill speed on crushing efficiency.

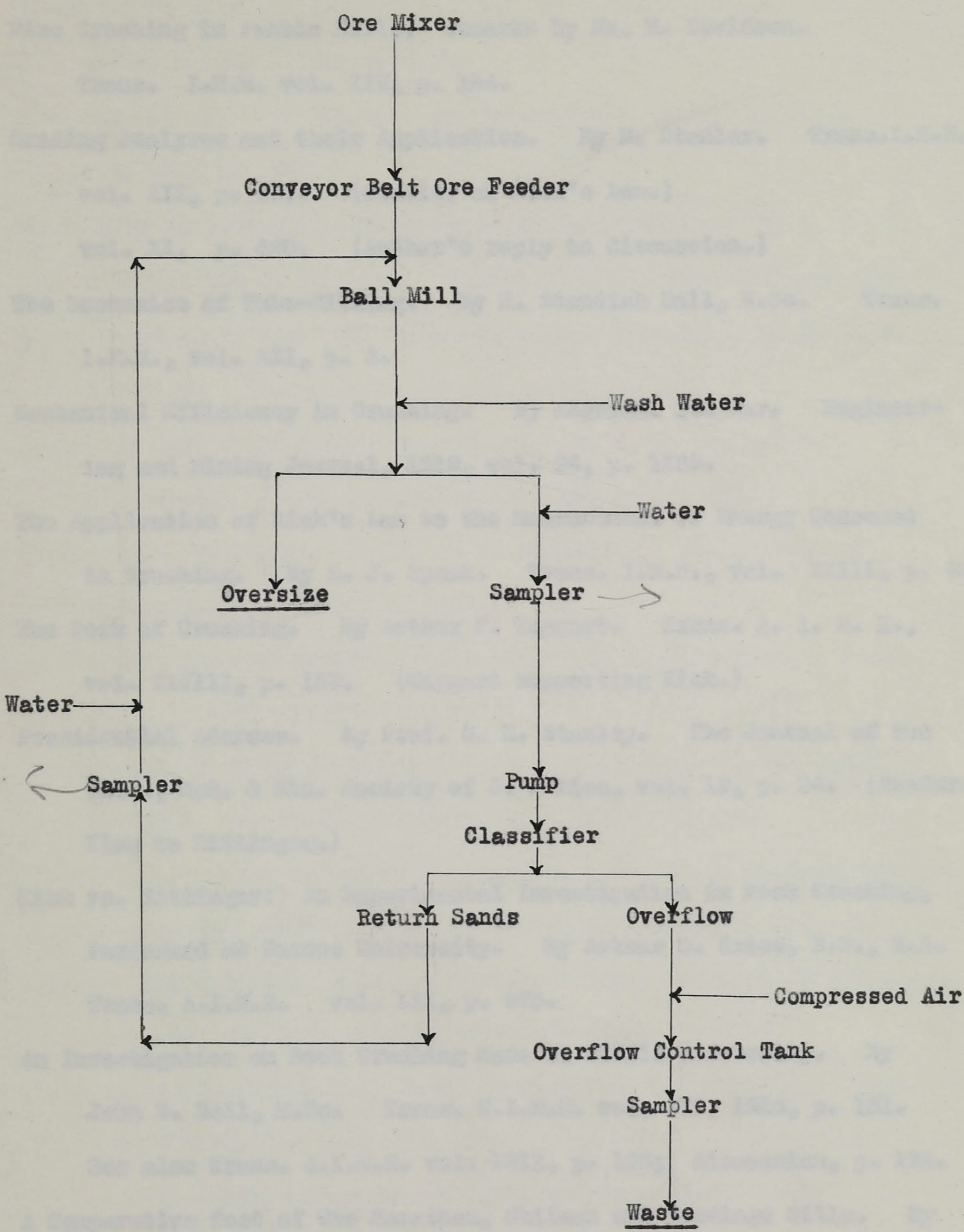
In the course of this investigation many improvements have been made in the plant and equipment.

The maximum efficiency for the mill was found to occur at a speed of rotation of about 39 R.P.M.

The range of speeds, for the most reliable tests, varied from 39 to 52 R.P.M., with relative mechanical efficiencies of about 700 to 456 surface units respectively.

It has been clearly shown that an increase in the speed of rotation causes a decrease in the relative mechanical efficiency of the mill.

It is considered that this investigation is not complete and some suggestions for its continuance have been put forward.



FLOW SHEET OF GRINDING CIRCUIT

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RESULTS

Mill Test No. 1 Date Dec. 22nd, 1934 Page

CRUSHING MEDIA.

587	Lbs.	$1\frac{1}{2}$	Inch
578	Lbs.	$1\frac{1}{4}$	Inch
	Lbs.		Inch
	Lbs.		Inch

Total 1165 Lbs. --------

Mill Volume------ 10 Cu. Ft.

Occupy 40 Percent Mill Vol.

MILL.

Pulp Percent Water.
Percent Solids.

Speed -------- 28.5 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 50.3%

Oversize 1 Dry Lbs.per Hr.
\+
Water--- 2 --- Lbs.per Hr.

CLASSIFIER.

Slope-------		Inches per Foot.
Strokes ----	26	Per Minute.
Return Sand-	52	Dry Lbs. per Hr.
+		
Water ------		Lbs. per Hour.

Overflow

Solids---	224	Dry Lbs. per Hr.
Water----	696	Pounds per Hour.

Liquid-Solid Ratio 3.11 : 1

BELT FEEDER.

Vernier Setting --------	4
Feed-Dry Pounds per Hr.-	222
Strokes per minute------	41.0
Pounds per Stroke-------	0.090

TIME.

Duration of Test	5.0	Hours.
Preparat. Period	3.0	Hours.
Sampling Period	2.0	Hours.

WATER

		At Start.		At End.
No.1 Cock (Feed Water) Dial Setting-------	3.15	Lbs. per Hr.	88	Lbs. per Hr. Not
No.2 Cock (To Classifier) Dial Setting-------	2.20	Lbs. per Hr.	66	Lbs. per Hr. Meas-
No.3 Cock (to Mill Disch.) Dial Setting-------	5.50	Lbs. per Hr.	535	Lbs. per Hr. ured.
		Total per Hr.	689	Total per Hr.

POWER.

220 Volts. 15.0 Amps. Wattmeter 3.48 KWH per Hr.

Input to Motor 4.66 H.P. Motor Efficiency 75.3 Percent.

Power Delivered to Mill --------------------	3.51	H.P.
Power lost in Mill Bearings, Drive Gear, Etc.	0.65	H.P. Est:
Power absorbed in Crushing -----------------	2.86	H.P.

Mill Test No. 2 Date Dec. 22nd, 1933 Page

CRUSHING MEDIA.	MILL.
587 Lbs. $1\frac{1}{8}$ Inch 578 Lbs. $1\frac{1}{4}$ Inch Lbs. Inch Lbs. Inch	Pulp Percent Water. Percent Solids.
Total 1165 Lbs. --------	Speed -------- 28.35 R.P.M. Critical Speed 56.7 R.P.M. Percent of Crit. Speed 50.1%
Mill Volume------ 10 Cu. Ft. Occupy 40 Percent Mill Vol.	Oversize 7 Dry Lbs.per Hr. + Water--- 4 --- Lbs.per Hr.

CLASSIFIER.	BELT FEEDER.
Slope------- Inches per Foot. Strokes ---- 26 Per Minute. Return Sand- 220 Dry Lbs. per Hr. + Water ------ Lbs. per Hour.	Vernier Setting -------- 8 Feed-Dry Pounds per Hr.- 315 Strokes per minute------ 41.3 Pounds per Stroke------- 0.127
Overflow Solids--- 323 Dry Lbs. per Hr. Water----1012 Pounds per Hour. Liquid-Solid Ratio 3.15 : 1	TIME. Duration of Test 7.0 Hours. Preparat. Period 4.0 Hours. Sampling Period 3.0 Hours.

WATER

		At Start.	At End.
No.1 Cock (Feed Water) Dial Setting-------	3.6	Lbs. per Hr. 130	Lbs. per Hr. Not
No.2 Cock (To Classifier) Dial Setting-------	4.5	Lbs. per Hr. 458	Lbs. per Hr. Meas-
No.3 Cock (to Mill Disch.) Dial Setting-------	5.0	Lbs. per Hr. 442	Lbs. per Hr. ured.
		Total per Hr. 1030	Total per Hr.

POWER.

220 Volts. 16.0 Amps. Wattmeter 3.70 KWH per Hr.

Input to Motor 4.96 H.P. Motor Efficiency 75.4 Percent.

Power Delivered to Mill -------------------- 3.74 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 0.65 H.P. Est:
Power absorbed in Crushing ----------------- 3.09 H.P.

Mill Test No. 3 Date Jan. 19th, 1934. Page

CRUSHING MEDIA.

587 Lbs. 1½ Inch
578 Lbs. 1¼ Inch
Lbs. Inch
Lbs. Inch

Total 1165 Lbs. --------

Mill Volume------ 10 Cu. Ft.

Occupy 40 Percent Mill Vol.

MILL.

Pulp Percent Water.
Percent Solids.

Speed -------- 28.4 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 50.2%

Oversize 30 Dry Lbs.per Hr.
+
Water--- 13 --- Lbs.per Hr.

CLASSIFIER.

Slope------- Inches per Foot.
Strokes ---- 25.9 Per Minute.
Return Sand- 127 Dry Lbs. per Hr.
+
Water ------ Lbs. per Hour.

Overflow
Solids--- 301 Dry Lbs. per Hr.
Water---- 585 Pounds per Hour.

Liquid-Solid Ratio 1.94 : 1

BELT FEEDER.

Vernier Setting -------- 8
Feed-Dry Pounds per Hr.- 325
Strokes per minute------ 41.0
Pounds per Stroke------- 0.1321

TIME.

Duration of Test 6 Hours.
Preparat. Period 3 Hours.
Sampling Period 3 Hours.

WATER

		At Start.		At End.	
No.1 Cock (Feed Water) Dial Setting-------	3.9	Lbs. per Hr.	Est: 157	Lbs. per Hr.	140
No.2 Cock (To Classifier) Dial Setting-------	---	Lbs. per Hr.	---	Lbs. per Hr.	---
No.3 Cock (to Mill Disch.) Dial Setting-------	5.2	Lbs. per Hr.	480	Lbs. per Hr.	488
		Total per Hr.	637	Total per Hr.	628

POWER.

220 Volts. 14.5 Amps. Wattmeter 3.33 KWH per Hr.

Input to Motor 4.46 H.P. Motor Efficiency 75.8 Percent.

Power Delivered to Mill -------------------- 3.38 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 0.65 H.P. Est:
Power absorbed in Crushing ------------------ 2.73 H.P.

Mill Test No. 4 Date Jan 26th, 1934 Page

CRUSHING MEDIA.

587 Lbs. 1½ Inch
578 Lbs. 1¼ Inch
Lbs. Inch
Lbs. Inch

Total 1165 Lbs. --------

Mill Volume------ 10 Cu. Ft.

Occupy 40 Percent Mill Vol.

MILL.

Pulp Percent Water.
Percent Solids.

Speed -------- 28.4 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 50.2%

Oversize 4 Dry Lbs.per Hr.
+
Water--- 4 --- Lbs.per Hr.

CLASSIFIER.

Slope------- Inches per Foot.
Strokes ---- 26.0 Per Minute.
Return Sand- 38 Dry Lbs. per Hr.
+
Water ------ Lbs. per Hour.

Overflow
Solids--- 220 Dry Lbs. per Hr.
Water---- 438 Pounds per Hour.

Liquid-Solid Ratio 1.99 : 1

BELT FEEDER.

Vernier Setting -------- 4
Feed-Dry Pounds per Hr.- 224
Strokes per minute------ 40.70
Pounds per Stroke------- 0.0917

TIME.

Duration of Test 6.0 Hours.
Preparat. Period 4.0 Hours.
Sampling Period 2.0 Hours.

WATER

		At Start.		At End.
No.1 Cock (Feed Water) Dial Setting-------	3.35	Lbs. per Hr.	105	Lbs. per Hr.
No.2 Cock (To Classifier) Dial Setting-------	----	Lbs. per Hr.	----	Lbs. per Hr.
No.3 Cock (to Mill Disch.) Dial Setting-------	4.5	Lbs. per Hr.	339	Lbs. per Hr.
		Total per Hr.	444	Total per Hr.

POWER.

220 Volts. 14.8 Amps. Wattmeter 3.41 KWH per Hr.

Input to Motor 4.57 H.P. Motor Efficiency 75.7 Percent.

Power Delivered to Mill -------------------- 3.46 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 0.65 H.P. Est:
Power absorbed in Crushing ----------------- 2.81 H.P.

Mill Test No. 5 Date Feb. 12th, 1934 Page

CRUSHING MEDIA.	MILL.
587 Lbs. $1\frac{1}{2}$ Inch 578 Lbs. $1\frac{1}{4}$ Inch Lbs. Inch Lbs. Inch	Pulp Percent Water. Percent Solids.
Total 1165 Lbs. --------	Speed -------- 28.5 R.P.M. Critical Speed 56.7 R.P.M. Percent of Crit. Speed 50.3%
Mill Volume------ 10 Cu. Ft. Occupy 40 Percent Mill Vol.	Oversize 1 Dry Lbs.per Hr. + Water--- 1 --- Lbs.per Hr.

CLASSIFIER.	BELT FEEDER.
Slope------- Inches per Foot. Strokes ----26.25 Per Minute. Return Sand- 1 Dry Lbs. per Hr. + Water ------ Lbs. per Hour.	Vernier Setting -------- 3 Feed-Dry Pounds per Hr.- 197 Strokes per minute------ 40.60 Pounds per Stroke------- 0.0809
Overflow Solids--- 193 Dry Lbs. per Hr. Water---- 382 Pounds per Hour. Liquid-Solid Ratio 1.98 : 1	TIME. Duration of Test 6.0 Hours. Preparat. Period 3.0 Hours. Sampling Period 3.0 Hours.

WATER

		At Start.		At End.	
No.1 Cock (Feed Water) Dial Setting-------	3.1	Lbs. per Hr.	80	Lbs. per Hr.	69
No.2 Cock (To Classifier) Dial Setting-------	---	Lbs. per Hr.	--	Lbs. per Hr.	--
No.3 Cock (to Mill Disch.) Dial Setting-------	4.4	Lbs. per Hr.	293	Lbs. per Hr.	293
		Total per Hr.	373	Total per Hr.	362

POWER.

220 Volts. 14.3 Amps. Wattmeter 3.27 KWH per Hr.

Input to Motor 4.38 H.P. Motor Efficiency 75.8 Percent.

Power Delivered to Mill -------------------- 3.32 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 0.65 H.P. Est.
Power absorbed in Crushing ----------------- 2.67 H.P.

Mill Test No. 6 Date Feb. 21st, 1934 Page

CRUSHING MEDIA.

587 Lbs. 1½ Inch
578 Lbs. 1¼ Inch
Lbs. Inch
Lbs. Inch

Total 1165 Lbs. --------

Mill Volume------ 10 Cu. Ft.

Occupy 40 Percent Mill Vol.

MILL.

Pulp Percent Water.
Percent Solids.

Speed --------- 28.5 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 50.3%

Oversize 1 Dry Lbs. per Hr.
+
Water--- 3 --- Lbs. per Hr.

CLASSIFIER.

Slope------- Inches per Foot.
Strokes ---26.25 Per Minute.
Return Sand- 18 Dry Lbs. per Hr.
+
Water ------ Lbs. per Hour.

Overflow
Solids--- 188 Dry Lbs. per Hr.
Water---- 362 Pounds per Hour.

Liquid-Solid Ratio 1.93 : 1

BELT FEEDER.

Vernier Setting --------3
Feed-Dry Pounds per Hr.-196
Strokes per minute------40.45
Pounds per Stroke-------0.0807

TIME.

Duration of Test 5 Hours.
Preparat. Period 2 Hours.
Sampling Period 3 Hours.

WATER

		At Start.		At End.
No.1 Cock (Feed Water) Dial Setting-------	2.8	Lbs. per Hr.	82	Lbs. per Hr.
No.2 Cock (To Classifier) Dial Setting-------	---	Lbs. per Hr.	--	Lbs. per Hr.
No.3 Cock (to Mill Disch.) Dial Setting-------	4.4	Lbs. per Hr.	293	Lbs. per Hr.
		Total per Hr.	375	Total per Hr.

POWER.

220 Volts. 14.0 Amps. Wattmeter 3.23 KWH per Hr.

Input to Motor 4.33 H.P. Motor Efficiency 75.2 Percent.

Power Delivered to Mill -------------------- 3.26 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 0.65 H.P. Est:
Power absorbed in Crushing ---------------- 2.61 H.P.

Mill Test No. 7 Date April 10th, 1934 Page

CRUSHING MEDIA.

587 Lbs. 1 1/8 Inch
578 Lbs. 1 1/4 Inch
Lbs. Inch
Lbs. Inch

Total 1165 Lbs. --------

Mill Volume------ 10 Cu. Ft.

Occupy 40 Percent Mill Vol.

MILL.

Pulp Percent Water.
Percent Solids.

Speed -------- R.P.M.
Critical Speed R.P.M.
Percent of Crit. Speed

Oversize Dry Lbs. per Hr.
+
Water--- --- Lbs. per Hr.

CLASSIFIER.

Slope------- Inches per Foot.
Strokes ---- Per Minute.
Return Sand- Dry Lbs. per Hr.
+
Water ------ Lbs. per Hour.

Overflow
Solids--- Dry Lbs. per Hr.
Water---- Pounds per Hour.

Liquid-Solid Ratio : 1

BELT FEEDER.

Vernier Setting --------
Feed-Dry Pounds per Hr.-
Strokes per minute------
Pounds per Stroke-------

TIME.

Duration of Test Hours.
Preparat. Period Hours.
Sampling Period Hours.

WATER

		At Start. Lbs. per Hr.		At End. Lbs. per Hr.	
No.1 Cock (Feed Water) Dial Setting-------	3.4	Lbs. per Hr.	142	Lbs. per Hr.	135
No.2 Cock (To Classifier) Dial Setting-------	---	Lbs. per Hr.	---	Lbs. per Hr.	---
No.3 Cock (to Mill Disch.) Dial Setting-------	4.2	Lbs. per Hr.	267	Lbs. per Hr.	263
		Total per Hr.	409	Total per Hr.	398

POWER.

Volts. Amps. Wattmeter KWH per Hr.

Input to Motor H.P. Motor Efficiency Percent.

Power Delivered to Mill -------------------- H.P.
Power lost in Mill Bearings, Drive Gear, Etc. H.P.
Power absorbed in Crushing ----------------- H.P.

Mill Test No. 8 Date April 17th, 1934 Page

CRUSHING MEDIA.

587	Lbs.	$1\frac{1}{2}$	Inch
578	Lbs.	$1\frac{1}{4}$	Inch
	Lbs.		Inch
	Lbs.		Inch

Total 1165 Lbs. --------

Mill Volume------ 10 Cu. Ft.

Occupy 40 Percent Mill Vol.

MILL.

Pulp Percent Water.
Percent Solids.

Speed -------- 39.33 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 69.3%

Oversize 2 Dry Lbs.per Hr.
+
Water--- 1 --- Lbs.per Hr.

CLASSIFIER.

Slope------- Inches per Foot.
Strokes ---- 26.1 Per Minute.
Return Sand- 21 Dry Lbs. per Hr.
+
Water ------ Lbs. per Hour.

Overflow
Solids--- 156 Dry Lbs. per Hr.
Water---- 299 Pounds per Hour.

Liquid-Solid Ratio 1.92 : 1

BELT FEEDER.

Vernier Setting -------- 1.5
Feed-Dry Pounds per Hr.- 155
Strokes per minute------ 39.50
Pounds per Stroke------- 0.0654

TIME.

Duration of Test 6.0 Hours.
Preparat. Period 2.5 Hours.
Sampling Period 3.5 Hours.

WATER

		At Start.	At End.
No.1 Cock (Feed Water) Dial Setting-------	3.0	Lbs. per Hr. 103	Lbs. per Hr. 94
No.2 Cock (To Classifier) Dial Setting-------		Lbs. per Hr. ---	Lbs. per Hr. --
No.3 Cock (to Mill Disch.) Dial Setting-------	3.9	Lbs. per Hr. 205	Lbs. per Hr. 206
		Total per Hr. 308	Total per Hr. 300

POWER.

214 Volts. 19.0 Amps. Wattmeter 4.18 KWH per Hr.

Input to Motor 5.60 H.P. Motor Efficiency 72.6 Percent.

Power Delivered to Mill -------------------- 4.06 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 0.98 H.P.
Power absorbed in Crushing ----------------- 3.08 H.P.

Mill Test No. 9 Date April 18th, 1934. Page

CRUSHING MEDIA.

587	Lbs.	$1\frac{1}{8}$	Inch
578	Lbs.	$1\frac{3}{4}$	Inch
	Lbs.		Inch
	Lbs.		Inch

Total 1165 Lbs. --------

Mill Volume------ 10 Cu. Ft.

Occupy 40 Percent Mill Vol.

MILL.

Pulp Percent Water.
Percent Solids.

Speed -------- 39.1 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 68.9%

Oversize 3 Dry Lbs. per Hr.
+
Water--- 2 --- Lbs. per Hr.

CLASSIFIER.

Slope------- Inches per Foot.
Strokes ---- 26.0 Per Minute.
Return Sand- Dry Lbs. per Hr.
+
Water ------ Lbs. per Hour.

Overflow
Solids--- 168 Dry Lbs. per Hr.
Water---- 343 Pounds per Hour.

Liquid-Solid Ratio 2.04 : 1

BELT FEEDER.

Vernier Setting -------- 1.8
Feed-Dry Pounds per Hr.- 169
Strokes per minute------39.84
Pounds per Stroke------- 0.0719

TIME.

Duration of Test 5.0 Hours.
Preparat. Period 3.5 Hours.
Sampling Period 1.5 Hours.

WATER

		At Start.	At End.
No.1 Cock (Feed Water) Dial Setting-------	3.2	Lbs. per Hr. 123	Lbs. per Hr. 119
No.2 Cock (To Classifier) Dial Setting-------	---	Lbs. per Hr. ---	Lbs. per Hr. ---
No.3 Cock (to Mill Disch.) Dial Setting-------	4.0	Lbs. per Hr. 223	Lbs. per Hr. 226
		Total per Hr. 346	Total per Hr. 345

POWER.

214 Volts. 19.0 Amps. Wattmeter 4.16 KWH per Hr.

Input to Motor 5.57 H.P. Motor Efficiency 72.1 Percent.

Power Delivered to Mill -------------------- 4.02 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 0.97 H.P.
Power absorbed in Crushing ----------------- 3.05 H.P.

Mill Test No. 10 Date April 23rd, 1934. Page

CRUSHING MEDIA.

587 Lbs.	$1\frac{1}{2}$	Inch
578 Lbs.	$1\frac{3}{4}$	Inch
Lbs.		Inch
Lbs.		Inch

Total 1165 Lbs. --------

Mill Volume------ 10 Cu. Ft.

Occupy 40 Percent Mill Vol.

MILL.

Pulp Percent Water.
Percent Solids.

Speed -------- 39.1 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 68.9%

Oversize 3 Dry Lbs. per Hr.
+
Water--- 2 --- Lbs. per Hr.

CLASSIFIER.

Slope------- Inches per Foot.
Strokes ---- 25.9 Per Minute.
Return Sand- 35 Dry Lbs. per Hr.
+
Water ------ Lbs. per Hour.

Overflow
Solids---177 Dry Lbs. per Hr.
Water----364 Pounds per Hour.

Liquid-Solid Ratio 2.06 : 1

BELT FEEDER.

Vernier Setting -------- 1.4
Feed-Dry Pounds per Hr.- 177
Strokes per minute------ 39.75
Pounds per Stroke------- 0.0814

TIME.

Duration of Test 4.5 Hours.
Preparat. Period 2.0 Hours.
Sampling Period 2.5 Hours.

WATER

		At Start.		At End.	
No. 1 Cock (Feed Water) Dial Setting-------	3.2	Lbs. per Hr.	122	Lbs. per Hr.	121
No. 2 Cock (To Classifier) Dial Setting-------	---	Lbs. per Hr.	---	Lbs. per Hr.	---
No. 3 Cock (to Mill Disch.) Dial Setting-------	4.1	Lbs. per Hr.	240	Lbs. per Hr.	242
		Total per Hr.	362	Total per Hr.	363

POWER.

214 Volts. 19.0 Amps. Wattmeter 4.23 KWH per Hr.

Input to Motor 5.67 H.P. Motor Efficiency 73.1 Percent.

Power Delivered to Mill -------------------- 4.14 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 0.97 H.P.
Power absorbed in Crushing ----------------- 3.17 H.P.

Mill Test No. 11 Date April 25th, 1934. Page

CRUSHING MEDIA.

587 Lbs. 1½ Inch
578 Lbs. 1¾ Inch
Lbs. Inch
Lbs. Inch

Total 1165 Lbs. --------

Mill Volume------ 10 Cu. Ft.

Occupy 40 Percent Mill Vol.

MILL.

Pulp Percent Water.
Percent Solids.

Speed -------- 39.0 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 68.7%

Oversize 2 Dry Lbs. per Hr.
+
Water--- 1 --- Lbs. per Hr.

CLASSIFIER.

Slope------- Inches per Foot.
Strokes ---- 25.85 Per Minute.
Return Sand- 20 Dry Lbs. per Hr.
+
Water ------ Lbs. per Hour.

Overflow
Solids--- 162 Dry Lbs. per Hr.
Water---- 317 Pounds per Hour.

Liquid-Solid Ratio 1.96 : 1

BELT FEEDER.

Vernier Setting -------- 0.7
Feed-Dry Pounds per Hr.- 163
Strokes per minute------ 39.60
Pounds per Stroke------- 0.0686

TIME.

Duration of Test 3 Hours.
Preparat. Period 1 Hours.
Sampling Period 2 Hours.

WATER

		At Start.		At End.	
No.1 Cock (Feed Water) Dial Setting-------	3.05	Lbs. per Hr.	105	Lbs. per Hr.	103
No.2 Cock (To Classifier) Dial Setting-------	----	Lbs. per Hr.	---	Lbs. per Hr.	---
No.3 Cock (to Mill Disch.) Dial Setting-------	3.97	Lbs. per Hr.	214	Lbs. per Hr.	215
		Total per Hr.	319	Total per Hr.	318

POWER.

214 Volts. 19.5 Amps. Wattmeter 4.24 KWH per Hr.

Input to Motor 5.68 H.P. Motor Efficiency 73.1 Percent.

Power Delivered to Mill -------------------- 4.15 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 0.97 H.P.
Power absorbed in Crushing ----------------- 3.18 H.P.

Mill Test No. 11A   Date April 25th, 1934. Page

CRUSHING MEDIA.

587 Lbs. 1½ Inch
578 Lbs. 1¼ Inch
Lbs. Inch
Lbs. Inch

Total 1165 Lbs. --------

Mill Volume------ 10 Cu. Ft.

Occupy 40 Percent Mill Vol.

MILL.

Pulp Percent Water.
Percent Solids.

Speed -------- 39.1 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 68.9%

Oversize 2 Dry Lbs.per Hr.
+
Water--- 1 --- Lbs.per Hr.

CLASSIFIER.

Slope------- Inches per Foot.
Strokes ---- 26.35 Per Minute.
Return Sand- 29 Dry Lbs. per Hr.
+
Water ------ Lbs. per Hour.

Overflow
Solids--- 155 Dry Lbs. per Hr.
Water---- 320 Pounds per Hour.

Liquid-Solid Ratio 2.06 : 1

BELT FEEDER.

Vernier Setting -------- 0.4
Feed-Dry Pounds per Hr.- 153
Strokes per minute------ 39.85
Pounds per Stroke------- 0.0641

TIME.

Duration of Test 4 Hours.
Preparat. Period 2 Hours.
Sampling Period 2 Hours.

WATER

		At Start.		At End.	
No.1 Cock (Feed Water)					
Dial Setting-------	3.05	Lbs. per Hr.	105	Lbs. per Hr.	103
No.2 Cock (To Classifier)					
Dial Setting-------	----	Lbs. per Hr.	---	Lbs. per Hr.	---
No.3 Cock (to Mill Disch.)					
Dial Setting-------	3.97	Lbs. per Hr.	214	Lbs. per Hr.	215
		Total per Hr.	319	Total per Hr.	318

POWER.

214 Volts. 19.25 Amps.   Wattmeter 4.22 KWH per Hr.

Input to Motor 5.65 H.P.   Motor Efficiency 73.1 Percent.

Power Delivered to Mill -------------------- 4.13 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 0.97 H.P.
Power absorbed in Crushing ----------------- 3.16 H.P.

Mill Test No. 12 Date April 27th, 1934. Page

CRUSHING MEDIA.	MILL.
587 Lbs. 1½ Inch 578 Lbs. 1¾ Inch Lbs. Inch Lbs. Inch	Pulp Percent Water. Percent Solids.
Total 1165 Lbs.	Speed -------- 28.45 R.P.M. Critical Speed 56.7 R.P.M. Percent of Crit. Speed 50.2
Mill Volume------ 10 Cu. Ft. Occupy 40 Percent Mill Vol.	Oversize 8 Dry Lbs.per Hr. + Water--- 5 --- Lbs.per Hr.

CLASSIFIER.	BELT FEEDER.
Slope------- Inches per Foot. Strokes ---- 26.25 Per Minute. Return Sand- 42 Dry Lbs. per Hr. + Water ------ Lbs. per Hour.	Vernier Setting Mark off Scale Feed-Dry Pounds per Hr.- 112 Strokes per minute------39.45 Pounds per Stroke------- 0.0473
Overflow Solids--- 105 Dry Lbs. per Hr. Water---- 226 Pounds per Hour. Liquid-Solid Ratio 2.15 : 1	TIME. Duration of Test 9.0 Hours. Preparat. Period 7.0 Hours. Sampling Period 2.0 Hours.

WATER

		At Start.		At End.
No.1 Cock (Feed Water) Dial Setting-------	2.75	Lbs. per Hr.	75	Lbs. per Hr. Not
No.2 Cock (To Classifier) Dial Setting-------	----	Lbs. per Hr.	--	Lbs. per Hr. Meas-
No.3 Cock (to Mill Disch.) Dial Setting-------	3.6	Lbs. per Hr.	150	Lbs. per Hr. ured.
		Total per Hr.	225	Total per Hr.

POWER.

214 Volts. 13.75 Amps. Wattmeter 3.01 KWH per Hr.

Input to Motor 4.03 H.P. Motor Efficiency 74.1 Percent.

Power Delivered to Mill ----------------------	2.99	H.P.
Power lost in Mill Bearings, Drive Gear, Etc.	0.65	H.P. Est.
Power absorbed in Crushing ------------------	2.34	H.P.

Mill Test No. 13 Date April 27th, 19 34. Page

CRUSHING MEDIA.

587 Lbs. 1½ Inch
578 Lbs. 1¼ Inch
Lbs. Inch
Lbs. Inch

Total 1165 Lbs. --------

Mill Volume------ 10 Cu. Ft.

Occupy 40 Percent Mill Vol.

MILL.

Pulp Percent Water.
Percent Solids.

Speed -------- 39.5 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 69.6%

Oversize 2 Dry Lbs. per Hr.
+
Water--- 2 --- Lbs. per Hr.

CLASSIFIER.

Slope------- Inches per Foot.
Strokes ---- 26.50 Per Minute.
Return Sand- 17 Dry Lbs. per Hr.
+
Water ------ Lbs. per Hour.

Overflow
Solids--- 150 Dry Lbs. per Hr.
Water---- 312 Pounds per Hour.

Liquid-Solid Ratio 2.08 : 1

BELT FEEDER.

Vernier Setting -------- 0.44
Feed-Dry Pounds per Hr.- 155
Strokes per minute------ 39.70
Pounds per Stroke------- 0.0651

TIME.

Duration of Test 3.17 Hours.
Preparat. Period 0.67 Hours.
Sampling Period 2.50 Hours.

WATER

	At Start.	At End.
No. 1 Cock (Feed Water) Dial Setting------- 3.05	Lbs. per Hr. Not	Lbs. per Hr. 103
No. 2 Cock (To Classifier) Dial Setting------- ----	Lbs. per Hr. Meas-	Lbs. per Hr. ---
No. 3 Cock (to Mill Disch.) Dial Setting------- 3.95	Lbs. per Hr. ured.	Lbs. per Hr. 215
	Total per Hr. ---	Total per Hr. 318

POWER.

214 Volts. 19.0 Amps. Wattmeter 4.15 KWH per Hr.

Input to Motor 5.56 H.P. Motor Efficiency 72.6 Percent.

Power Delivered to Mill -------------------- 4.04 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 0.98 H.P.
Power absorbed in Crushing ----------------- 3.06 H.P.

Mill Test No. 14 Date April 29th, 1934. Page

CRUSHING MEDIA.	MILL.
587 Lbs. 1½ Inch 578 Lbs. 1¾ Inch Lbs. Inch Lbs. Inch	Pulp Percent Water. Percent Solids.
Total 1165 Lbs. --------	Speed -------- 44.07 R.P.M. Critical Speed 56.7 R.P.M. Percent of Crit. Speed 77.8%
Mill Volume------ 10 Cu. Ft. Occupy 40 Percent Mill Vol.	Oversize 1 Dry Lbs.per Hr. + Water--- 2 --- Lbs.per Hr.

CLASSIFIER.	BELT FEEDER.
Slope------- Inches per Foot. Strokes ---- 26.1 Per Minute. Return Sand- 14 Dry Lbs. per Hr. + Water ------ Lbs. per Hour.	Vernier Setting -------- 0.4 Feed-Dry Pounds per Hr.- 159 Strokes per minute-----39.57 Pounds per Stroke-------0.0670
Overflow Solids--- 159 Dry Lbs. per Hr. Water---- 315 Pounds per Hour. Liquid-Solid Ratio 1.98 : 1	TIME. Duration of Test 4.67 Hours. Preparat. Period 2.67 Hours. Sampling Period 2.00 Hours.

WATER

			At Start.		At End.	
No.1 Cock (Feed Water)						
Dial Setting-------	3.05		Lbs. per Hr.	96	Lbs. per Hr.	103
No.2 Cock (To Classifier)						
Dial Setting-------	----		Lbs. per Hr.	---	Lbs. per Hr.	---
No.3 Cock (to Mill Disch.)						
Dial Setting-------	3.97		Lbs. per Hr.	210	Lbs. per Hr.	215
			Total per Hr.		Total per Hr.	318

POWER.

214 Volts. 20.25 Amps. Wattmeter 4.47 KWH per Hr.

Input to Motor 5.99 H.P. Motor Efficiency 79.8 Percent.

Power Delivered to Mill -------------------- 4.78 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 1.10 H.P.
Power absorbed in Crushing ----------------- 3.68 H.P.

Mill Test No. 15 Date April 29th, 1934. Page

CRUSHING MEDIA.	MILL.
587 Lbs. $1\frac{1}{2}$ Inch 578 Lbs. $1\frac{1}{4}$ Inch Lbs. Inch Lbs. Inch Total 1165 Lbs. -------- Mill Volume------ 10 Cu. Ft. Occupy 40 Percent Mill Vol.	Pulp Percent Water. Percent Solids. Speed -------- 47.5 R.P.M. Critical Speed 56.7 R.P.M. Percent of Crit. Speed 83.8% Oversize 1 Dry Lbs.per Hr. + Water--- 2 --- Lbs.per Hr.
CLASSIFIER. Slope------- Inches per Foot. Strokes ----26.58 Per Minute. Return Sand- 18 Dry Lbs. per Hr. + Water ------ Lbs. per Hour. Overflow Solids--- 155 Dry Lbs. per Hr. Water---- 311 Pounds per Hour. Liquid-Solid Ratio 2.01 : 1	**BELT FEEDER.** Vernier Setting --------0.4 Feed-Dry Pounds per Hr.-157 Strokes per minute-----39.65 Pounds per Stroke-------0.0660 **TIME.** Duration of Test 2.30 Hours. Preparat. Period 0.30 Hours. Sampling Period 2.00 Hours.

WATER

		At Start.	At End.
No.1 Cock (Feed Water) Dial Setting-------	3.05	Lbs. per Hr. 96	Lbs. per Hr. 103
No.2 Cock (To Classifier) Dial Setting-------	----	Lbs. per Hr. ---	Lbs. per Hr. ---
No.3 Cock (to Mill Disch.) Dial Setting-------	3.97	Lbs. per Hr. 210	Lbs. per Hr. 215
		Total per Hr. 306	Total per Hr. 318

POWER.

214 Volts. 21.75 Amps. Wattmeter 4.76 KWH per Hr.

Input to Motor 6.38 H.P. Motor Efficiency 79.2 Percent.

Power Delivered to Mill -------------------- 5.05 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 1.18 H.P.
Power absorbed in Crushing ----------------- 3.87 H.P.

Mill Test No. 16 Date April 29th, 1934. Page

CRUSHING MEDIA.

587 Lbs. 1½ Inch
578 Lbs. 1¾ Inch
Lbs. Inch
Lbs. Inch

Total 1165 Lbs. --------

Mill Volume------ 10 Cu. Ft.

Occupy 40 Percent Mill Vol.

MILL.

Pulp Percent Water.
Percent Solids.

Speed -------- 52.0 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 91.8%

Oversize 1 Dry Lbs.per Hr.
+
Water--- 1 --- Lbs.per Hr.

CLASSIFIER.

Slope------- Inches per Foot.
Strokes ---- 26.27 Per Minute.
Return Sand- 15 Dry Lbs. per Hr.
+
Water ------ Lbs. per Hour.

Overflow
Solids--- 154 Dry Lbs. per Hr.
Water---- 318 Pounds per Hour.

Liquid-Solid Ratio 2.06 : 1

BELT FEEDER.

Vernier Setting -------- 0.4
Feed-Dry Pounds per Hr.- 158
Strokes per minute------ 39.79
Pounds per Stroke------- 0.0662

TIME.

Duration of Test 2.08 Hours.
Preparat. Period 1.00 Hours.
Sampling Period 1.08 Hours.

WATER

		At Start.		At End.	
No.1 Cock (Feed Water) Dial Setting-------	3.05	Lbs. per Hr.	96	Lbs. per Hr.	103
No.2 Cock (To Classifier) Dial Setting-------	----	Lbs. per Hr.	--	Lbs. per Hr.	---
No.3 Cock (to Mill Disch.) Dial Setting-------	3.97	Lbs. per Hr.	210	Lbs. per Hr.	215
		Total per Hr.	306	Total per Hr.	318

POWER.

214 Volts. 23.5 Amps. Wattmeter 5.21 KWH per Hr.

Input to Motor 6.98 H.P. Motor Efficiency 78.8 Percent.

Power Delivered to Mill -------------------- 5.50 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 1.25 H.P.
Power absorbed in Crushing ----------------- 4.25 H.P.

Mill Test No. 17 Date April 29th, 1934. Page

CRUSHING MEDIA.	MILL.
587 Lbs. 1½ Inch 578 Lbs. 1¼ Inch Lbs. Inch Lbs. Inch	Pulp Percent Water. Percent Solids.
Total 1165 Lbs. --------	Speed -------- 51.9 R.P.M. Critical Speed 56.7 R.P.M. Percent of Crit. Speed 91.7%
Mill Volume------ 10 Cu. Ft. Occupy 40 Percent Mill Vol.	Oversize 1 Dry Lbs.per Hr. + Water--- 1 --- Lbs.per Hr.
CLASSIFIER.	BELT FEEDER.
Slope------- Inches per Foot. Strokes ----26.45 Per Minute. Return Sand- 20 Dry Lbs. per Hr. + Water ------ Lbs. per Hour.	Vernier Setting Est: --------1.3 Feed-Dry Pounds per Hr.- 130 Strokes per minute------39.77 Pounds per Stroke------- 0.0545
Overflow Solids--- 130 Dry Lbs. per Hr. Water---- 282 Pounds per Hour. Liquid-Solid Ratio 2.17 : 1	TIME. Duration of Test 3.60 Hours. Preparat. Period 2.03 Hours. Sampling Period 1.57 Hours.

WATER

		At Start.	Est:	At End.	
No.1 Cock (Feed Water) Dial Setting-------	3.0	Lbs. per Hr.	91	Lbs. per Hr.	98
No.2 Cock (To Classifier) Dial Setting-------	---	Lbs. per Hr.	---	Lbs. per Hr.	---
No.3 Cock (to Mill Disch.) Dial Setting-------	3.82	Lbs. per Hr.	181	Lbs. per Hr.	191
		Total per Hr.	272	Total per Hr.	289

POWER.

214 Volts. 23.5 Amps. Wattmeter 5.16 KWH per Hr.

Input to Motor 6.91 H.P. Motor Efficiency 78.8 Percent.

Power Delivered to Mill -------------------- 5.44 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 1.25 H.P.
Power absorbed in Crushing ----------------- 4.19 H.P.

Mill Test No. 1 Cont'd. Date Dec. 22nd, 1933 .Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4						x 0.05 =	
6						x 0.06 =	
8						x 0.10 =	
10						x 0.12 =	
14	See					x 0.20 =	
20	Test		0.1	0.4		0.25	
28	No. 6		0.1	0.4		0.35	
35			0.2	1.0		0.50	
48			0.7	3.7		0.70	
65			2.3	9.7	0.4	1.00	0.4
100			11.0	29.6	5.3	1.40	7.4
150			12.2	23.7	11.0	2.00	22.0
200			16.1	14.6	16.5	2.90	47.8
- 200			57.3	16.9	66.8	14.00	935.2
Total		27	100.0	100.0	100.0	Overflow	1012.8

Mill Feed	Dry Tons per 24 H.	2.66
CLASSIFIER OVERFLOW (Finished Prod.)	" " " " "	2.69
Return Sand	" " " " "	0.62
Mill Discharge	" " " " "	3.31

Mechanical Value of Classifier Overflow	Surface	Units	1013
" " " Feed	"	"	27
Crushing Work done per Ton	"	"	986
" " " " 24 Hours	"	"	2622
Crush. Work per H.P. (Total Power to Mill)	"	"	748
" " " H.P. (Crushing Power Only)	"	"	918

Mill Test No. 2 Cont'd. Date Dec. 22nd. 1933 Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4						x 0.05 =	
6						x 0.06 =	
8						x 0.10 =	
10			0.1	0.1		x 0.12 =	
14	See		0.2	0.5		x 0.20 =	
20	Test		0.2	0.6		0.25	
28	No. 6		0.3	0.8		0.35	
35			0.6	1.6		0.50	
48			2.1	5.4		0.70	
65			5.7	12.5	0.7	1.00	0.7
100			18.5	35.3	8.0	1.40	11.2
150			16.9	19.9	15.1	2.00	30.2
200			16.1	11.5	17.6	2.90	51.0
- 200			39.3	11.8	58.6	14.00	820.4
Total		27	100.0	100.0	100.0	Overflow	913.5

Mill Feed	Dry Tons per 24 H.	3.70
CLASSIFIER OVERFLOW (Finished Prod.)	" " " " "	3.87
Return Sand	" " " " "	2.64
Mill Discharge	" " " " "	6.51

Mechanical Value of Classifier Overflow	Surface Units	913
" " " Feed	" "	27
Crushing Work done per Ton	" "	886
" " " " 24 Hours	" "	3278
Crush. Work per H.P. (Total Power to Mill)	" "	886
" " " H.P. (Crushing Power Only)	" "	1060

Mill Test No. 3 Cont'd. Date Jan 19th, 1934 Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4						x 0.05 =	
6						x 0.06 =	
8						x 0.10 =	
10			0.2	0.6		x 0.12 =	
14	See		0.5	1.6		x 0.20 =	
20	Test		0.5	1.7		0.25	
28	No. 6		0.5	1.6		0.35	
35			0.7	2.5		0.50	
48			2.3	6.8		0.70	
65			5.1	12.1	2.2	1.00	2.2
100			15.1	28.9	11.5	1.40	16.1
150			15.8	17.0	15.2	2.00	30.4
200			16.1	11.7	17.6	2.90	51.0
- 200			43.2	15.5	53.5	14.00	749.0
Total		27	100.0	100.0	100.0	Overflow	848.7

Mill Feed	Dry Tons per 24 H.	3.54
CLASSIFIER OVERFLOW (Finished Prod.)	" " " " "	3.61
Return Sand	" " " " "	1.52
Mill Discharge	" " " " "	5.13

Mechanical Value of Classifier Overflow	Surface Units	849
" " " Feed	" "	27
Crushing Work done per Ton	" "	822
" " " " 24 Hours	" "	2920
Crush. Work per H.P. (Total Power to Mill)	" "	861
" " " H.P. (Crushing Power Only)	" "	1065

Mill Test No. 4 Cont'd. Date Jan. 26th, 1934 Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4						x 0.05 =	
6						x 0.06 =	
8						x 0.10 =	
10			0.1	0.2		x 0.12 =	
14	See		0.2	1.1		x 0.20 =	
20	Test		0.1	1.4		0.25	
28	NO. 6		0.2	1.5		0.35	
35			0.2	2.5		0.50	
48			1.0	7.7		0.70	
65			2.7	13.9	1.0	1.00	1.0
100			9.1	26.0	6.6	1.40	9.2
150			12.7	15.3	11.8	2.00	23.6
200			16.4	11.4	16.6	2.90	48.1
- 200			57.3	19.0	64.0	14.00	896.0
Total		27	100.0	100.0	100.0	Overflow	977.9

Mill Feed	Dry Tons per 24 H.	2.64
CLASSIFIER OVERFLOW (Finished Prod.)	" " " " "	2.64
Return Sand	" " " " "	0.46
Mill Discharge	" " " " "	3.10

Mechanical Value of Classifier Overflow	Surface Units	978
" " " Feed	" "	27
Crushing Work done per Ton	" "	951
" " " " 24 Hours	" "	2510
Crush. Work per H.P. (Total Power to Mill)	" "	726
" " " H.P. (Crushing Power Only)	" "	894

Mill Test No. 5 Cont'd. Date Feb. 12th, 1934 Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4						x 0.05 =	
6						x 0.06 =	
8						x 0.10 =	
10						x 0.12 =	
14	See					x 0.20 =	
20	Test			0.4		0.25	
28	No. 6		0.1	0.8		0.35	
35			0.1	1.7		0.50	
48			0.7	5.8		0.70	
65			1.7	15.3	1.2	1.00	1.2
100			7.0	29.4	6.4	1.40	9.0
150			10.8	16.5	11.5	2.00	23.0
200			15.2	10.9	16.2	2.90	47.0
- 200			64.4	19.2	64.7	14.00	905.8
Total		27	100.0	100.0	100.0	Overflow	986.0

Mill Feed	Dry Tons per 24 H.	2.35
CLASSIFIER OVERFLOW (Finished Prod.)	" " " " "	2.32
Return Sand	" " " " "	0.01
Mill Discharge	" " " " "	2.33

Mechanical Value of Classifier Overflow	Surface Units	986
" " " Feed	" "	27
Crushing Work done per Ton	" "	959
" " " " 24 Hours	" "	2252
Crush. Work per H.P. (Total Power to Mill)	" "	679
" " " H.P. (Crushing Power Only)	" "	844

Mill Test No. 6 Cont'd. Date Feb. 21st, 1934 Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4	4.0	0.2				x 0.05 =	
6	22.6	1.4				x 0.06 =	
8	23.5	2.3				x 0.10 =	
10	17.0	2.0				x 0.12 =	
14	8.6	1.7				x 0.20 =	
20	6.8	1.7		0.6		0.25	
28	4.1	1.4	0.1	0.7		0.35	
35	3.2	1.6	0.1	1.4		0.50	
48	3.6	2.5	0.5	6.0		0.70	
65	3.3	3.6	1.6	14.7	0.3	1.00	0.3
100	2.4	3.4	6.5	30.3	4.4	1.40	6.2
150	0.4	0.8	10.4	15.4	10.1	2.00	20.2
200	0.1	0.3	15.4	10.8	15.6	2.90	45.2
- 200	0.3	4.2	65.4	20.1	69.6	14.00	975.8
Total	100.0	27.1	100.0	100.0	100.0	Overflow	1047.7

Mill Feed	Dry Tons per 24 H.	2.34
CLASSIFIER OVERFLOW (Finished Prod.)	" " " " "	2.26
Return Sand	" " " " "	0.22
Mill Discharge	" " " " "	2.48

Mechanical Value of Classifier Overflow	Surface	Units	1048
" " " Feed	"	"	27
Crushing Work done per Ton	"	"	1021
" " " " 24 Hours	"	"	2390
Crush. Work per H.P. (Total Power to Mill)	"	"	734
" " " H.P. (Crushing Power Only)	"	"	916

Mill Test No. 7 Cont'd. Date April 10th, 19 34 Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4	6.0	0.3				x 0.05 =	
6	27.5	1.6				x 0.06 =	
8	18.5	1.8				x 0.10 =	
10	15.0	1.8	0.2			x 0.12 =	
14	7.7	1.5	0.1	0.7		x 0.20 =	
20	6.3	1.6	0.2	1.6		0.25	
28	4.2	1.5	0.2	1.3		0.35	
35	3.4	1.7	0.3	1.9		0.50	
48	3.9	2.7	0.7	6.0		0.70	
65	3.5	3.8	1.9	13.4	0.4	1.00	0.4
100	2.8	3.9	6.4	28.6	3.4	1.40	4.8
150	0.7	1.4	9.2	15.8	8.3	2.00	16.6
200	0.3	0.9	13.2	9.8	13.4	2.90	38.9
- 200	0.2	2.8	67.6	21.0	74.5	14.00	1043.0
Total	100.0	27.2	100.0	100.1	100.0	Overflow	1103.7

Mill Feed Dry Tons per 24 H.	[illegible]
CLASSIFIER OVERFLOW (Finished Prod.) " " " " "	[illegible]
Return Sand " " " " "	[illegible]
Mill Discharge " " " " "	[illegible]

Mechanical Value of Classifier Overflow Surface Units	[illegible]
" " " Feed " "	[illegible]
Crushing Work done per Ton " "	[illegible]
" " " " 24 Hours " "	[illegible]
Crush. Work per H.P. (Total Power to Mill) " "	[illegible]
" " " H.P. (Crushing Power Only) " "	[illegible]

Mill Test No. 8 Cont'd. Date April 17th, 1934 Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4	4.7	0.2				x 0.05 =	
6	28.7	1.7				x 0.06 =	
8	18.4	1.8				x 0.10 =	
10	16.5	2.0	0.1			x 0.12 =	
14	7.9	1.6	0.1			x 0.20 =	
20	6.0	1.5	0.1	1.0		0.25	
28	3.9	1.4	0.1	1.7		0.35	
35	3.2	1.6	0.1	1.8		0.50	
48	3.5	2.4	0.5	5.1		0.70	
65	3.3	3.6	1.3	12.2	0.1	1.00	0.1
100	2.7	3.8	4.6	30.5	1.8	1.40	2.5
150	0.7	1.4	7.6	16.5	6.1	2.00	12.2
200	0.3	0.9	11.8	9.5	11.3	2.90	32.8
- 200	0.2	2.8	73.7	21.8	80.7	14.00	1129.8
Total	100.0	26.7	100.0	100.1	100.0	Overflow	1177.4

Mill Feed	Dry Tons per 24 H.	1.84
CLASSIFIER OVERFLOW (Finished Prod.)	" " " " "	1.87
Return Sand	" " " " "	0.25
Mill Discharge	" " " " "	2.12

Mechanical Value of Classifier Overflow	Surface Units	1177
" " " Feed	" "	27
Crushing Work done per Ton	" "	1150
" " " " 24 Hours	" "	2118
Crush. Work per H.P. (Total Power to Mill)	" "	522
" " " H.P. (Crushing Power Only)	" "	688

Mill Test No. 9 Cont'd. Date April 18th, 1934. Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4						x 0.05 =	
6						x 0.06 =	
8						x 0.10 =	
10						x 0.12 =	
14	See		No	0.3		x 0.20 =	
20	Test		Sample.	1.8		0.25	
28	No. 8			1.4		0.35	
35				1.9		0.50	
48				5.1		0.70	
65				11.8	0.2	1.00	0.2
100				28.8	2.5	1.40	3.5
150				15.9	7.4	2.00	14.8
200				10.6	12.9	2.90	37.4
- 200				22.4	77.0	14.00	1078.0
Total		27		100.0	100.0	Overflow	1133.9

Mill Feed	Dry Tons per 24 H.	1.99
CLASSIFIER OVERFLOW (Finished Prod.)	" " " " "	2.02
Return Sand	" " " " "	----
Mill Discharge	" " " " "	No Screen Analysis.

Mechanical Value of Classifier Overflow	Surface Units	1134
" " " Feed	" "	27
Crushing Work done per Ton	" "	1107
" " " " 24 Hours	" "	2204
Crush. Work per H.P. (Total Power to Mill)	" "	548
" " " H.P. (Crushing Power Only)	" "	723

Mill Test No. 10 Cont'd. Date April 23rd, 1934. Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4						x 0.05 =	
6						x 0.06 =	
8						x 0.10 =	
10						x 0.12 =	
14	See		0.6	0.7		x 0.20 =	
20	Test		0.2	1.6		0.25	
28	No. 8		0.2	1.4		0.35	
35			0.3	1.9		0.50	
48			0.8	5.1		0.70	
65			1.9	12.4	0.1	1.00	0.1
100			6.2	30.1	2.3	1.40	3.2
150			8.7	15.5	7.5	2.00	15.0
200			12.7	10.6	12.5	2.90	36.2
- 200			68.4	20.8	77.6	14.00	1086.4
Total		27	100.0	100.0	100.0	Overflow	1140.9

Mill Feed	Dry Tons per 24 H.	2.09
CLASSIFIER OVERFLOW (Finished Prod.)	" " " " "	2.12
Return Sand	" " " " "	0.42
Mill Discharge	" " " " "	2.54

Mechanical Value of Classifier Overflow	Surface Units	1141
" " " Feed	" "	27
Crushing Work done per Ton	" "	1114
" " " " 24 Hours	" "	2330
Crush. Work per H.P. (Total Power to Mill)	" "	563
" " " H.P. (Crushing Power Only)	" "	736

Mill Test No. 11 Cont'd. Date April 25th, 19 34. Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4						x 0.05 =	
6						x 0.06 =	
8						x 0.10 =	
10						x 0.12 =	
14	See		0.1	0.1		x 0.20 =	
20	Test		0.1	1.7		0.25	
28	No. 8		0.1	1.5		0.35	
35			0.2	1.9		0.50	
48			0.6	5.6		0.70	
65			1.3	12.9	0.1	1.00	0.1
100			4.5	30.3	2.0	1.40	2.8
150			6.8	14.2	6.1	2.00	12.2
200			12.1	9.2	11.1	2.90	32.2
- 200			74.2	22.6	80.7	14.00	1129.8
Total		27	100.0	100.0	100.0	Overflow	1177.1

Mill Feed	Dry Tons per 24 H.	1.93
CLASSIFIER OVERFLOW (Finished Prod.)	" " " " "	1.94
Return Sand	" " " " "	0.24
Mill Discharge	" " " " "	2.18

Mechanical Value of Classifier Overflow	Surface Units	1177
" " " Feed	" "	27
Crushing Work done per Ton	" "	1150
" " " " 24 Hours	" "	2220
Crush. Work per H.P. (Total Power to Mill)	" "	535
" " " H.P. (Crushing Power Only)	" "	698

Mill Test No. **11A** Cont'd.   Date **April 25th, 19 34.** Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4						x 0.05 =	
6						x 0.06 =	
8						x 0.10 =	
10						x 0.12 =	
14	**See**		**0.1**			x 0.20 =	
20	**Test**		**0.2**	**1.7**		0.25	
28	**No. 8**		**0.1**	**1.5**		0.35	
35			**0.2**	**1.8**		0.50	
48			**0.5**	**5.1**		0.70	
65			**1.2**	**12.2**	**0.1**	1.00	**0.1**
100			**4.3**	**29.4**	**1.6**	1.40	**2.2**
150			**6.8**	**15.3**	**6.1**	2.00	**12.2**
200			**10.8**	**9.6**	**10.7**	2.90	**31.0**
- 200			**75.8**	**23.4**	**81.5**	14.00	**1141.0**
Total		**27**	**100.0**	**100.0**	**100.0**	Overflow	**1186.5**

Mill Feed	Dry Tons per 24 H.	**1.81**
CLASSIFIER OVERFLOW (Finished Prod.)	" " " " "	**1.86**
Return Sand	" " " " "	**0.35**
Mill Discharge	" " " " "	**2.21**

Mechanical Value of Classifier Overflow	Surface Units	**1187**
" " " Feed	" "	**27**
Crushing Work done per Ton	" "	**1160**
" " " " 24 Hours	" "	**2100**
Crush. Work per H.P. (Total Power to Mill)	" "	**509**
" " " H.P. (Crushing Power Only)	" "	**665**

Mill Test No. 12 Cont'd. Date April 27th, 1934. Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4						x 0.05 =	
6						x 0.06 =	
8						x 0.10 =	
10			0.6			x 0.12 =	
14	See		0.6	0.3		x 0.20 =	
20	Test		0.5	4.8		0.25	
28	No. 8		0.4	3.6		0.35	
35			0.4	2.8		0.50	
48			1.0	5.4		0.70	
65			2.0	10.0		1.00	
100			5.9	25.7	1.0	1.40	1.4
150			8.3	15.8	4.1	2.00	8.2
200			12.9	9.3	9.4	2.90	27.3
- 200			67.4	22.3	85.5	14.00	1197.0
Total		27	100.0	100.0	100.0	Overflow	1233.9

Mill Feed	Dry Tons per 24 H.	1.25
CLASSIFIER OVERFLOW (Finished Prod.)	" " " " "	1.26
Return Sand	" " " " "	0.50
Mill Discharge	" " " " "	1.76

Mechanical Value of Classifier Overflow	Surface Units	1234
" " " Feed	" "	27
Crushing Work done per Ton	" "	1207
" " " " 24 Hours	" "	1509
Crush. Work per H.P. (Total Power to Mill)	" "	505
" " " H.P. (Crushing Power Only)	" "	645

Mill Test No. 16 Cont'd. Date April 27th, 19 34. Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4						x 0.05 =	
6						x 0.06 =	
8						x 0.10 =	
10			0.1			x 0.12 =	
14	See		0.1	0.4		x 0.20 =	
20	Test		0.1	2.5		0.25	
28	No. 8		0.1	1.5		0.35	
35			0.2	1.8		0.50	
48			0.5	5.1		0.70	
65			1.4	11.9	0.1	1.00	0.1
100			4.1	30.9	1.7	1.40	2.4
150			6.5	14.9	5.6	2.00	11.2
200			11.1	9.6	10.6	2.90	30.7
- 200			75.8	22.3	82.0	14.00	1148.0
Total		27	100.0	100.0	100.0	Overflow	1192.4
Mill Feed						Dry Tons per 24 H.	1.84
CLASSIFIER OVERFLOW (Finished Prod.)						" " " " "	1.80
Return Sand						" " " " "	0.21
Mill Discharge						" " " " "	2.01

Mechanical Value of Classifier Overflow	Surface Units	1192
" " " Feed	" "	27
Crushing Work done per Ton	" "	1165
" " " " 24 Hours	" "	2145
Crush. Work per H.P. (Total Power to Mill)	" "	531
" " " H.P. (Crushing Power Only)	" "	702

Mill Test No. **14** Cont'd. Date **April 29th, 1934.** Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4						x 0.05 =	
6						x 0.06 =	
8						x 0.10 =	
10			0.1			x 0.12 =	
14	See		0.1	0.2		x 0.20 =	
20	Test		0.1	1.2		0.25	
28	No. 8		0.1	1.1		0.35	
35			0.1	1.8		0.50	
48			0.4	5.4		0.70	
65			1.1	13.1	0.1	1.00	0.1
100			3.7	30.2	1.7	1.40	2.4
150			6.1	14.3	5.4	2.00	10.8
200			10.5	9.3	10.4	2.90	30.2
- 200			77.7	23.4	82.4	14.00	1153.6
Total		27	100.0	100.0	100.0	Overflow	1197.1

Mill Feed	Dry Tons per 24 H.	1.91
CLASSIFIER OVERFLOW (Finished Prod.)	" " " " "	1.91
Return Sand	" " " " "	0.17
Mill Discharge	" " " " "	2.08

Mechanical Value of Classifier Overflow	Surface Units	1197
" " " Feed	" "	27
Crushing Work done per Ton	" "	1170
" " " " 24 Hours	" "	2223
Crush. Work per H.P. (Total Power to Mill)	" "	465
" " " H.P. (Crushing Power Only)	" "	604

Mill Test No. 15 Cont'd. Date April 29th, 1934. Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4						x 0.05 =	
6						x 0.06 =	
8						x 0.10 =	
10			0.1			x 0.12 =	
14	See		0.0	0.2		x 0.20 =	
20	Test		0.1	1.1		0.25	
28	No. 8		0.1	1.0		0.35	
35			0.1	1.6		0.50	
48			0.5	4.9		0.70	
65			1.4	12.0	0.1	1.00	0.1
100			3.9	31.1	1.5	1.40	2.1
150			6.0	15.6	4.9	2.00	9.8
200			9.7	9.1	9.2	2.90	26.7
- 200			78.1	23.4	84.3	14.00	1180.2
Total		27	100.0	100.0	100.0	Overflow	1218.9

Mill Feed	Dry Tons per 24 H.	1.88
CLASSIFIER OVERFLOW (Finished Prod.)	" " " " "	1.86
Return Sand	" " " " "	0.21
Mill Discharge	" " " " "	2.07

Mechanical Value of Classifier Overflow	Surface Units	1219
" " " Feed	" "	27
Crushing Work done per Ton	" "	1192
" " " " 24 Hours	" "	2240
Crush. Work per H.P. (Total Power to Mill)	" "	443
" " " H.P. (Crushing Power Only)	" "	579

Mill Test No. 16 Cont'd. Date April 29th, 1934. Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4						x 0.05 =	
6						x 0.06 =	
8						x 0.10 =	
10						x 0.12 =	
14	See			0.2		x 0.20 =	
20	Test			1.4		0.25	
28	No. 8		0.1	1.2		0.35	
35			0.1	1.6		0.50	
48			0.5	5.0		0.70	
65			1.4	11.8	0.1	1.00	0.1
100			4.0	30.3	1.5	1.40	2.1
150			6.2	16.7	5.3	2.00	10.6
200			9.8	9.1	10.0	2.90	29.0
- 200			77.9	22.7	83.1	14.00	1163.4
Total		27	100.0	100.0	100.0	Overflow	1205.2

Mill Feed	Dry Tons per 24 H.	1.89
CLASSIFIER OVERFLOW (Finished Prod.)	" " " " "	1.85
Return Sand	" " " " "	0.18
Mill Discharge	" " " " "	2.03

Mechanical Value of Classifier Overflow	Surface Units	1205
" " " Feed	" "	27
Crushing Work done per Ton	" "	1178
" " " " 24 Hours	" "	2226
Crush. Work per H.P. (Total Power to Mill)	" "	405
" " " H.P. (Crushing Power Only)	" "	524

Mill Test No. 17 Cont'd. Date April 29th, 1934. Page

Mesh	Mill Feed % Wt.	Mech. Value S.U.	Mill Disch. % Wt.	Ret'n. Sand % Wt.	Classif. Overflow % Wt.	Surface Factor	Mech. Value S.U.
+ 4						x 0.05 =	
6						x 0.06 =	
8						x 0.10 =	
10			0.1			x 0.12 =	
14	See		0.1	0.1		x 0.20 =	
20	Test		0.1	1.2		0.25	
28	No. 8		0.1	1.3		0.35	
35			0.1	1.4		0.50	
48			0.5	4.3		0.70	
65			1.4	11.1		1.00	
100			4.2	29.4	0.8	1.40	1.1
150			6.1	19.3	3.9	2.00	7.8
200			8.7	9.2	8.2	2.90	23.8
- 200			78.6	22.7	87.1	14.00	1219.4
Total		27	100.0	100.0	100.0	Overflow	1252.1

Mill Feed	Dry Tons per 24 H.	1.56
CLASSIFIER OVERFLOW (Finished Prod.)	" " " " "	1.56
Return Sand	" " " " "	0.24
Mill Discharge	" " " " "	1.80

Mechanical Value of Classifier Overflow	Surface Units	1252
" " " Feed	" "	27
Crushing Work done per Ton	" "	1225
" " " " 24 Hours	" "	1911
Crush. Work per H.P. (Total Power to Mill)	" "	352
" " " H.P. (Crushing Power Only)	" "	456

CHECK ON TEST NO. 1

$$T = 222 \times \frac{(0.667 - 0.169)}{(0.573 - 0.169)} - 222$$

$$= \frac{222 \times 0.498}{0.404} = 274 - 222 = 52$$

Mill Discharge	=	274 lbs/hr.
Classifier Overflow	=	222 lbs/hr.
Sand Return	=	52 lbs/hr.

-200	274 x 0.573	=		157
	222 x 0.667	=	148)	157
	52 x 0.169	=	9)	
Plus	274 x 0.161	=		44.1
200	222 x 0.165	=	36.6)	44.2
	52 x 0.146	=	7.6)	
Plus	274 x 0.122	=		33.4
150	222 x 0.110	=	24.4)	36.7
	52 x 0.237	=	12.3)	
Plus	274 x 0.110	=		30.1
100	222 x 0.053	=	11.8)	27.2
	52 x 0.296	=	15.4)	

CHECK ON TEST NO. 2

$$T = 314 \times \frac{(0.586 - 0.118)}{(0.393 - 0.118)} - 314$$

$$= 314 \times \underline{9.468} - 314 = 534 - 314 = 220$$

Mill Discharge	=	534 lbs/hr.
Classifier Overflow	=	314 lbs/hr.
Return Sands	=	220 lbs/hr.

-200	534 x .393	=		210
	314 x .586	=	184)	210
	220 x .118	=	26)	
Plus 200	534 x .161	=		86
	314 x .176	=	55)	80
	220 x .115	=	25)	
Plus 150	534 x .169	=		90
	314 x .151	=	47)	90
	220 x .196	=	43)	
Plus 100	534 x .185	=		99
	314 x .080	=	25)	103
	220 x .353	=	78)	

CHECK ON TEST NO. 3

$$T = 338 \times \frac{(0.535 - 0.154)}{(0.431 - 0.154)} - 338$$

$$= 338 \times \frac{0.381}{0.277} - 338 = 465 - 338 = 127$$

Mill Discharge	=	465 lbs/hr.
Classifier Overflow	=	338 lbs/hr.
Return Sands	=	127 lbs/hr.

-200	465 x 0.431	=		200
	338 x 0.535	=	181)	200
	127 x 0.154	=	19)	
Plus	465 x 0.160	=		75.2
200	338 x 0.176	=	59.5)	75.6
	127 x 0.117	=	16.1)	
Plus	465 x 0.158	=		74.3
150	338 x 0.152	=	51.4)	72.9
	127 x 0.169	=	21.5)	
Plus	465 x 0.150	=		70.5
100	338 x 0.115	=	38.9)	75.5
	127 x 0.288	=	36.6)	

CHECK ON TEST NO. 4

$$T = 220 \times \frac{(0.640 - 0.190)}{(0.573 - 0.190)} - 220$$

$$= 220 \times \frac{0.450}{0.383} - 220 = 258 - 220 = 38$$

Mill Discharge	=	258 lbs/hr.
Classifier Overflow	=	220 lbs/hr.
Return Sands	=	38 lbs/hr.

-200	258 x 0.573	=		148
	220 x 0.640	=	141)	148
	38 x 0.190	=	7)	
Plus 200	258 x 0.164	=		42.3
	220 x 0.166	=	36.5)	40.8
	38 x 0.114	=	4.3)	
Plus 150	258 x 0.127	=		32.8
	220 x 0.118	=	26.0)	31.8
	38 x 0.153	=	5.8)	
Plus 100	258 x 0.091	=		23.5
	220 x 0.066	=	14.5)	24.4
	38 x 0.260	=	9.9)	

CHECK ON TEST NO. 5

$$T = 193 \times \frac{(0.647 - 0.193)}{0.644 - 0.193} - 193$$

$$= 193 \times \frac{0.454}{0.451} = 194 - 193 = 1$$

Mill Discharge	=	194 lbs/hr.
Classifier Overflow	=	193 lbs/hr.
Return Sands	=	1 lbs/hr.

-200	193 x 0.644	=		124
	192 x 0.647	=	124	
	1 x 0.193	=		
Plus 200	193 x 0.152	=		29.3
	192 x 0.162	=	31.1)	31.2
	1 x 0.109	=	0.1)	
Plus 150	193 x 0.108	=		20.8
	192 x 0.115	=	22.1)	22.3
	1 x 0.165	=	0.2)	
Plus 100	193 x 0.070	=		13.5
	192 x 0.064	=	13.4)	13.7
	1 x 0.294	=	0.3)	

CHECK ON TEST NO. 6

$$T = 188 \times \frac{(0.697 - 0.201)}{(0.654 - 0.201)} - 188$$

$$= 188 \times \frac{0.496}{0.453} - 188 = 206 - 188 = 18$$

Mill Discharge	=	206 lbs/hr.	
Classifier Overflow	=	188 lbs/hr.	
Return Sands	=	18 lbs/hr.	

-200	206 x 0.654	=		135
	188 x 0.697	=	131)	135
	18 x 0.201	=	4)	
Plus 200	206 x 0.154	=		31.7
	188 x 0.156	=	29.3)	31.2
	18 x 0.108	=	1.9)	
Plus 150	206 x 0.104	=		21.4
	188 x 0.101	=	19.0)	21.8
	18 x 0.154	=	2.8)	
Plus 100	206 x 0.065	=		13.4
	188 x 0.044	=	8.3)	13.8
	18 x 0.303	=	5.5)	

CHECK ON TEST NO. 8

$$T = 156 \times \frac{(0.807 - 0.218)}{(0.736 - 0.218)} - 156$$

$$= 156 \times \frac{0.589}{0.518} - 156 = 177 - 156 = 21$$

Mill Discharge	=	177 lbs/hr.
Classifier Overflow	=	156 lbs/hr.
Return Sands	=	21 lbs/hr.

-200	177 x 0.736	=		130
	156 x 0.807	=	126)	130
	21 x 0.216	=	4)	
Plus	177 x 0.117	=		20.7
200	156 x 0.113	=	17.6)	19.6
	21 x 0.095	=	2.0)	
Plus	177 x 0.074	=		13.1
150	156 x 0.061	=	9.5)	13.0
	21 x 0.165	=	3.5)	
Plus	177 x 0.048	=		8.5
100	156 x 0.018	=	2.8)	9.2
	21 x 0.305	=	6.4)	

CHECK ON TEST NO. 10.

$$T = 177 \times \frac{(0.778 - 0.208)}{(0.684 - 0.208)} - 177$$

$$= 177 \times \frac{0.510}{0.476} - 177 = 212 - 177 = 35$$

Mill Discharge	=	212 lbs/hr.
Classifier Overflow	=	177 lbs/hr.
Return Sands	=	35 lbs/hr.

-200	212 x 0.684	=		145
	177 x 0.778	=	138)	145
	35 x 0.208	=	7)	
Plus	212 x 0.127	=		26.9
200	177 x 0.123	=	21.8)	25.5
	35 x 0.106	=	3.7)	
Plus	212 x 0.087	=		18.4
150	177 x 0.075	=	13.3)	18.7
	35 x 0.155	=	5.4)	
Plus	212 x 0.062	=		13.1
100	177 x 0.023	=	4.1)	14.6
	35 x 0.301	=	10.5)	

CHECK ON TEST NO. 11

$$T = 162 \times \frac{(0.807 - 0.225)}{(0.742 - 0.225)} - 162$$

$$= 162 \times \frac{0.582}{0.517} - 162 = 182 - 162 = 20$$

Mill Discharge	=	182 lbs/hr.
Classifier Overflow	=	162 lbs/hr.
Return Sands	=	20 lbs/hr.

-200	182 x 0.742	=		135
	162 x 0.807	=	131)	135
	20 x 0.225	=	4)	
Plus 200	182 x 0.121	=		22.0
	162 x 0.111	=	18.0)	19.8
	20 x 0.089	=	1.8)	
Plus 150	182 x 0.068	=		12.4
	162 x 0.061	=	9.9)	12.7
	20 x 0.143	=	2.8)	
Plus 100	182 x 0.045	=		8.2
	162 x 0.020	=	3.2)	9.3
	20 x 0.305	=	6.1)	

CHECK ON TEST NO. 11A

$$T = 155 \times \frac{(0.855 - 0.234)}{(0.758 - 0.234)} - 155$$

$$= 155 \times \frac{0.621}{0.524} - 155 = 184 - 155 = 29$$

Mill Discharge	=	184 lbs/hr.	
Classifier Overflow	=	155 lbs/hr.	
Return Sands	=	29 lbs/hr.	

-200	184 x .758	=		139
	155 x .855	=	132)	139
	29 x .234	=	7)	
Plus	184 x .108	=		19.8
200	155 x .094	=	14.6)	17.5
	29 x .096	=	2.8)	
Plus	184 x .068	=		12.5
150	155 x .041	=	6.4)	
	29 x .153	=	4.4)	
Plus	184 x .043	=		7.9
100	155 x .010	=	1.5)	10.0
	29 x .294	=	8.5)	

CHECK ON TEST NO. 12

$$T = 105 \times \frac{(0.855 - 0.223)}{(0.674 - 0.223)} - 105$$

$$= 105 \times \frac{0.632}{0.451} - 105 = 147 - 105 = 42$$

Mill Discharge	=	147 lbs/hr.
Classifier Overflow	=	105 lbs/hr.
Return Sands	=	42 lbs/hr.

-200	147 x 0.674	=		99.1
	105 x 0.855	=	89.8)	99.2
	42 x 0.223	=	9.4)	
Plus 200	147 x 0.129	=		19.0
	105 x 0.094	=	9.9)	13.8
	42 x 0.093	=	3.9)	
Plus 150	147 x 0.083	=		12.2
	105 x 0.041	=	4.3)	10.9
	42 x 0.158	=	6.6)	
Plus 100	147 x 0.059	=		8.7
	105 x 0.010	=	1.0)	11.8
	42 x 0.257	=	10.8)	

CHECK ON TEST No. 13.

$$T = 150 \times \frac{(0.820 - 0.223)}{(0.758 - 0.223)} - 150$$

$$= 150 \times 0.597 - 150 = 167 - 150 = 17$$

Mill Discharge	=	167 lbs/hr.
Classifier Overflow	=	150 lbs/hr.
Return Sands	=	17 lbs/hr.

-200	167 x 0.758	=		126
	150 x 0.820	=	122)	126
	17 x 0.223	=	4)	
Plus	167 x 0.111	=		18.5
200	150 x 0.106	=	15.9)	17.4
	17 x 0.096	=	1.6)	
Plus	167 x 0.065	=		10.8
150	150 x 0.056	=	8.4)	10.9
	17 x 0.149	=	2.5)	
Plus	167 x 0.041	=		6.8
100	150 x 0.017	=	2.6)	7.7
	17 x 0.300	=	5.1)	

CHECK ON TEST NO. 14

$$T = 159 \times \frac{(0.824 - 0.234)}{(0.777 - 0.234)} - 159$$

$$= 159 \times \frac{0.590}{0.543} - 159 = 173 - 159 = 14$$

Mill Discharge	=	173 lbs/hr.
Classifier Overflow	=	159 lbs/hr.
Return Sands	=	14 lbs/hr.

-200	173 x 0.777	=		134
	159 x 0.824	=	131)	134
	14 x 0.234	=	3)	
Plus	173 x 0.105	=		18.2
200	159 x 0.104	=	16.5)	17.8
	14.x 0.093	=	1.3)	
Plus	173 x 0.061	=		10.5
150	159 x 0.086	=	8.6)	10.6
	14 x 0.020	=	2.0)	
Plus	173 x 0.064	=		6.4
100	159 x 0.027	=	2.7)	6.9
	14 x 0.042	=	4.2)	

CHECK ON TEST NO. 15

$$T = 155 \times \frac{(0.843 - 0.234)}{(0.781 - 0.234)} - 155$$

$$= 155 \times \frac{0.609}{0.547} - 155 = 173 - 155 = 18$$

Mill Discharge	=	173 lbs/hr.
Classifier Overflow	=	155 lbs/hr.
Return Sands	=	18 lbs/hr.

-200	173 x 0.781	=		135
	155 x 0.843	=	131)	135
	18 x 0.234	=	4)	
Plus 200	173 x 0.097	=		16.7
	155 x 0.092	=	14.5)	16.1
	18 x 0.091	=	1.6)	
Plus 150	173 x 0.060	=		10.4
	155 x 0.049	=	7.6)	10.4
	18 x 0.158	=	2.8)	
Plus 100	173 x 0.039	=		6.7
	155 x 0.015	=	2.2)	7.5
	18 x 0.311	=	5.3)	

CHECK ON TEST NO. 16

$$T = 154 \times \frac{(0.831 - 0.227)}{(0.779 - 0.227)} - 154$$

$$= 154 \times 0.604 - 154 = 168.5 - 154 = 14.5$$

Mill Discharge	=	168.5 lbs/hr.	
Classifier Overflow	=	154 lbs/hr.	
Return Sands	=	14.5 lbs/hr.	

-200	168.5 x 0.779	=		131
	154 x 0.831	=	128)	131
	14.5 x 0.227	=	3)	
Plus 200	168.5 x 0.098	=		16.5
	154 x 0.100	=	15.4)	16.7
	14.5 x 0.091	=	1.3)	
Plus 150	168.5 x 0.062	=		10.4
	154 x 0.053	=	8.2)	10.6
	14.5 x 0.167	=	2.4)	
Plus 100	168.5 x 0.040	=		6.7
	154 x 0.015	=	2.3)	6.7
	14.5 x 0.303	=	4.4)	

CHECK ON TEST NO. 17

$$T = 130 \times \frac{(0.871 - 0.227)}{(0.786 - 0.227)} - 130$$

$$= 130 \times \frac{0.644}{0.559} - 130 = 150 - 130 = 20$$

Mill Discharge	=	150 lbs/hr.
Classifier Overflow	=	130 lbs/hr.
Return Sands	=	20 lbs/hr.

-200	150 x 0.786	=		118
	130 x 0.871	=	113)	118
	20 x 0.227	=	5)	
Plus	150 x 0.087	=		13.0
200	130 x 0.082	=	10.7)	12.5
	20 x 0.092	=	1.8)	
Plus	150 x 0.061	=		9.2
150	130 x 0.039	=	5.1)	9.0
	20 x 0.193	=	3.9)	
Plus	150 x 0.042	=		6.3
100	130 x 0.008	=	1.0)	6.9
	20 x 0.294	=	5.9)	

APPENDIX

GENERAL LOG OF TESTS

Test No. 1.

Desired Conditions:-

Mill R.P.M.--28.5

Feed--220 lbs/hr.

%moisture in mill--30%

L.S. ratio overflow--3.00:1

After the mill had been running approximately one hour samples were commenced of the classifier overflow, mill discharge, and return sand.

The first sample showed the circuit had not yet been built up, so no further samples were taken for two hours.

The last two indicated that a balance had been established so the test was concluded.

Test No. 2. This followed No. 1 immediately.

It was decided to raise the tonnage in order to determine the capacity of the mill at the same speed.

Conditions:-

Mill R.P.M.--28.5

Feed--315 lbs/hr.

%moisture in mill--30%

L.S. ratio overflow--3:1

Approximately an hour was allowed before sampling, which was then carried out for four hours. No satisfactory results could be obtained the overflow varying from 276 to 347 lbs/hr. of solids, and no balance being reached.

Therefore it was decided that the liquid: solid ratio was too high.

Test No. 3.

The L:S:ratio was therefore reduced to approximately 2:1

Conditions:-

Mill R.P.M.--28.5

Feed--325 lbs/hr.

%moisture in mill--30%

L:S: ratio overflow 2:1

There was again a great uneveness shown in the overflow samples. Therefore it was decided to take tub samples of the overflow pulp. Two tub samples were taken at the same time as one from the sampler. These immediately showed that there was a very uneven discharge from the mill, consecutive samples, taken for seven minutes each, showing a variation in the amount of solids of as much as 40 lbs/hr.

Further the amount of oversize increased considerably, averaging about 28 lbs/hr.

This indicated that the mill must be overloaded.

Test No. 4.

The feed rate was therefore dropped considerably.

Conditions:-

Mill R.P.M.--28.5

Feed--225

% of moisture in mill--30%

L:S: Ratio--2:1

After a long preparatory period samples indicated an approach to a state of balance, but there still seemed to be a certain amount of uneveness in the flow. It was decided that the mill was still slightly overloaded and that a drop of about 25 lbs would probably give the capacity-point of the mill.

The oversize had been reduced to 4 lbs/hr.

Test No. 5.

Conditions:-

Mill R.P.M.--235

Feed--197 lbs/hr

% of moisture in mill--30%

L:S: ratio overflow--2:1

After two preliminary overflow samples, which gave low results, it was decided that there was something seriously in error with the equipment.

The balance of the test was spent in taking tub samples of the whole flow from the classifier overflow.

From nine tubs taken, the average amount of solids was 189 lbs/hr., but the extreme amounts were 158 and 222 lbs/hr.

The average was only three pounds less than the actual feed rate less the oversize. Therefore it was considered that an approximate state of balance had been reached, but that there was some condition causing a very uneven discharge from the mill.

Test No. 6.

It was decided to run another test similar to No. 5 with a careful check being maintained over all the operating details.

However, the results were very similar to those in No. 5.

During this test it was noted that the lifters on the quick-discharge end of the mill were not functioning properly.

The mill was taken down and this condition adjusted.

Further it was decided that there was not sufficient moisture in the mill pulp and this was raised from 30% to 40 % in subsequent tests.

At this time it was decided to build the Classifier Overflow Control Tank. Improvements were made in this after Tests 7, 8, and 9 had been run. It proved to be an addition to the plant of the greatest value.

Test No. 7.

This test was of no value, as it was found that the handle on the motor control switch had been shifted to a tap other than that desired.

Test No. 8.

Conditions:-

Mill R.P.M.--39

Feed--155 lbs/hr.

% of moisture in mill--40%

L:S: ratio overflow--2:1

In this test the speed was raised to 39 R.P.M.

A balance was reached and satisfactory results were obtained.

Test No. 9.

Conditions:-

Mill R.P.M.--39

Feed--169 lbs/hr.

% of moisture in mill--40%

L:S: ratio 2:1

The feed rate was raised a bit in this test.

Satisfactory results were again obtained.

Test No. 10.

Conditions:-

Mill R.P.M.--39

Feed--177 lbs/hr.

% of moisture in mill--40%

L:S: ratio overflow--2:1

The feed rate was again raised somewhat. Fairly satisfactory results were obtained, but there was some evidence of overloading.

Test No. 11 & 11A.

These were run under similar conditions to No. 10, except that the feed rate was dropped to 161 lbs/hr in No 11 and 151 lbs/hr. in No. 10.

This was done in an attempt to determine the point of maximum capacity at a speed of 39 R.P.M. for the mill.

Test No. 12.

After completing No. 11A, the pulleys on the mill and motor drives were changed to allow of greater speeds of rotation for the mill.

On starting Test No. 12 at a speed of 44 R.P.M. it was found that the grate of the mill was completely plugged.

After cleaning the grate it was decided to run one more test at 28.5 R.P.M. to see if the grate had been partly plugged in the previous tests at 39 R.P.M. Therefore, the final conditions for

Test No. 12 were:-

Mill R.P.M.--39

Feed--112 lbs/hr.

% of moisture in mill--40%

L:S: ratio--2:1

The feed rate was dropped considerably to make sure that the mill would not be overloaded.

Satisfactory results were obtained.

Test No. 13.

This was a check on No. 11A and gave satisfactory results.

Test No. 14.

Conditions:-

Mill R.P.M.--44

Feed--159 lbs/hr.

% of moisture in mill--40%

L:S: ratio--2:1

The speed was raised to 44 R.P.M., the other conditions being approximately the same.

The results were good.

Test No. 15.

Similar to test No. 14 only the Mill Speed was raised to 47.5 R.P.M.

Results good.

Test No. 16.

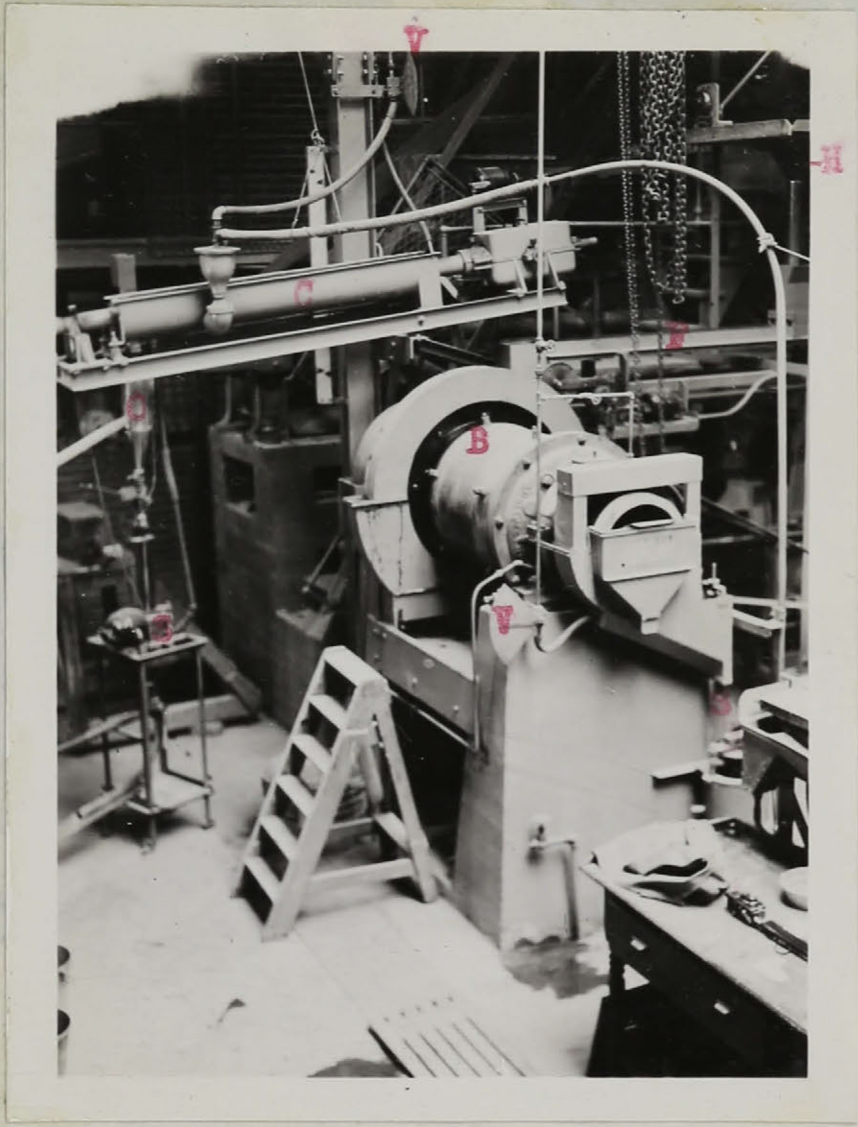
Conditions approximately similar once more, except that the mill speed was again increased this time to 52 R.P.M.

A balance was nearly reached, but there seemed some evidence of overloading.

Test No. 17.

Therefore, the feed rate was dropped considerably and the results then obtained were good.

P H O T O G R A P H S



No. 1

GENERAL VIEW OF MILLING PLANT

B - Ball Mill.

C - Classifier.

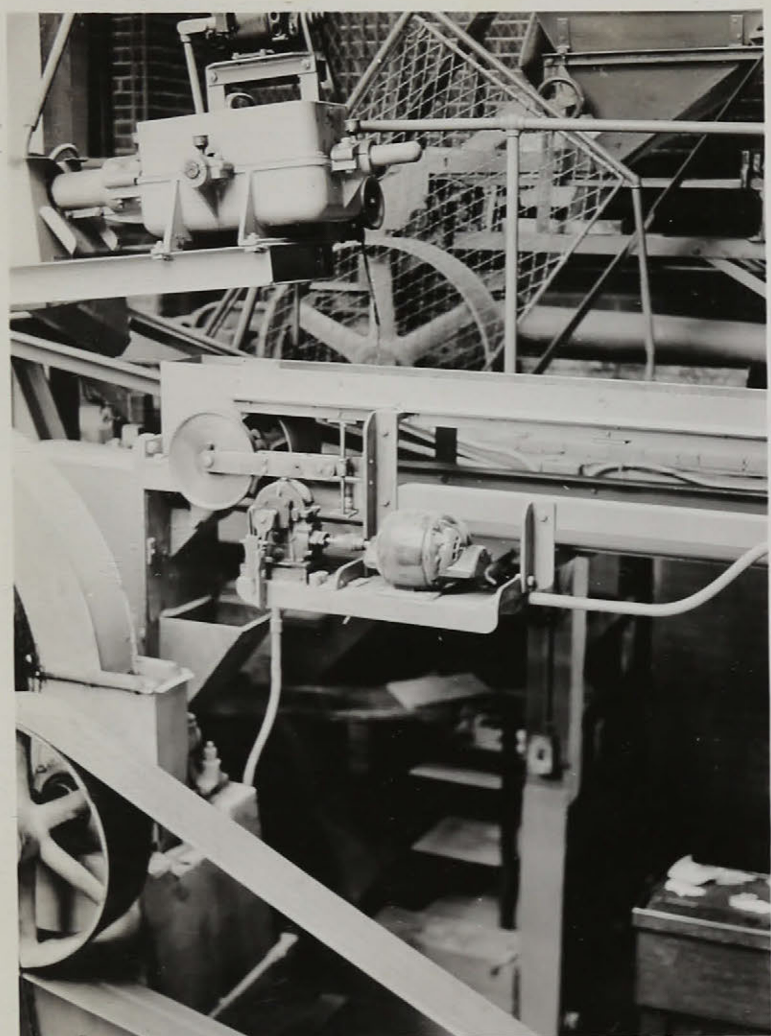
H - Hopper - Ore Feeder.

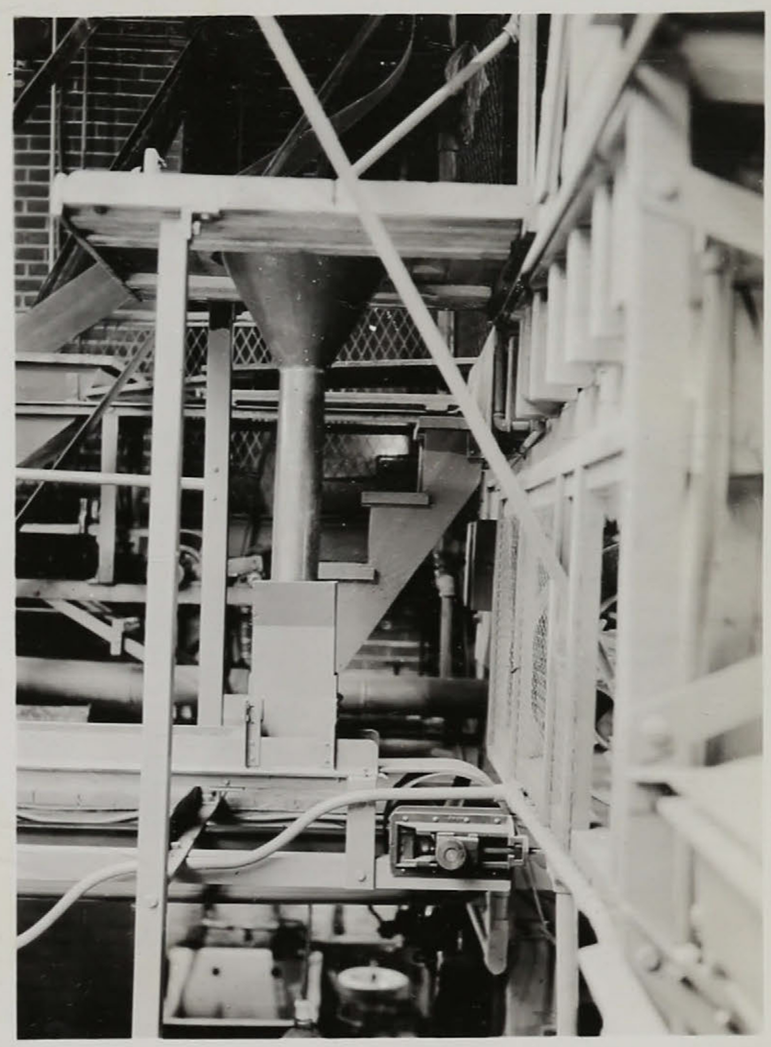
F - Conveyor Belt - Ore Feeder.

O - Classifier Overflow Control Tank.

S - Automatic Samplers.

V - Calibrated Valves on Water Supply.





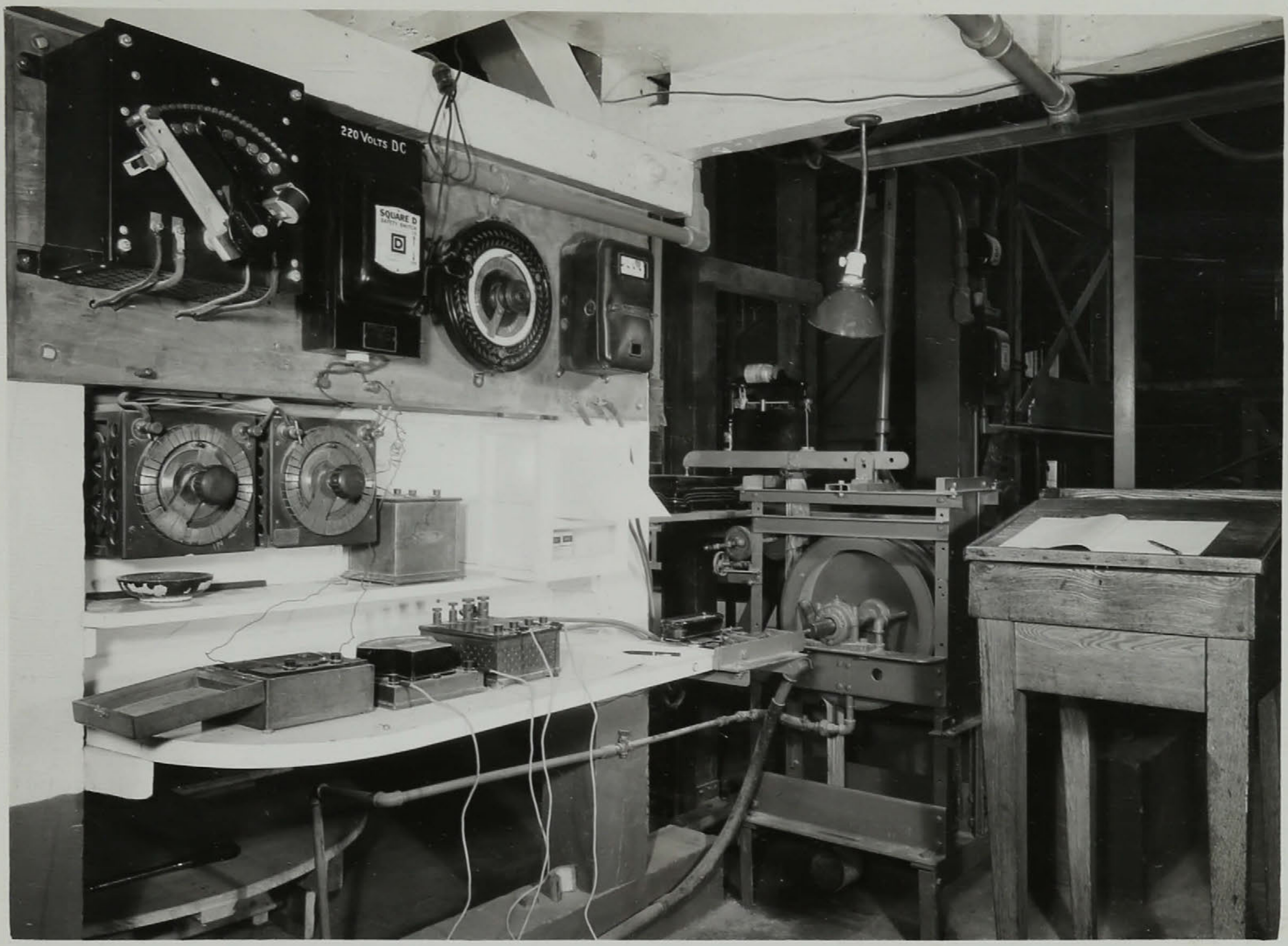
No. 2

No. 3

ORE FEED HOPPER AND CONVEYOR BELT

Showing the spillway into the mill, the cam-operated friction roller arm which drives the conveyor belt, and the driving mechanism of the classifier.

Showing the charging floor and the hopper by which the ore is fed onto the conveyor belt.



No. 4

CONTROL APPARATUS AND BELL BRAKE

(a)CONTROL APPARATUS.

Upper Panel, left to right:-

(1) Motor starting switch with variable resistance of 36 taps in series.

(2) Main switch in power line from power house.

(3) Smaller resistance of 21 taps in series with motor starting switch for fine adjustments of motor speed.

(4) Thompson integrating wattmeter.

Underneath Panel:-

(1) Two variable resistances, in series in the incoming power line, for control of voltage to the motor.

(2) Electrical recorders for registering mill revolutions, classifier strokes and strokes of conveyor belt arm.

On the Table:-

(1) Voltmeter.

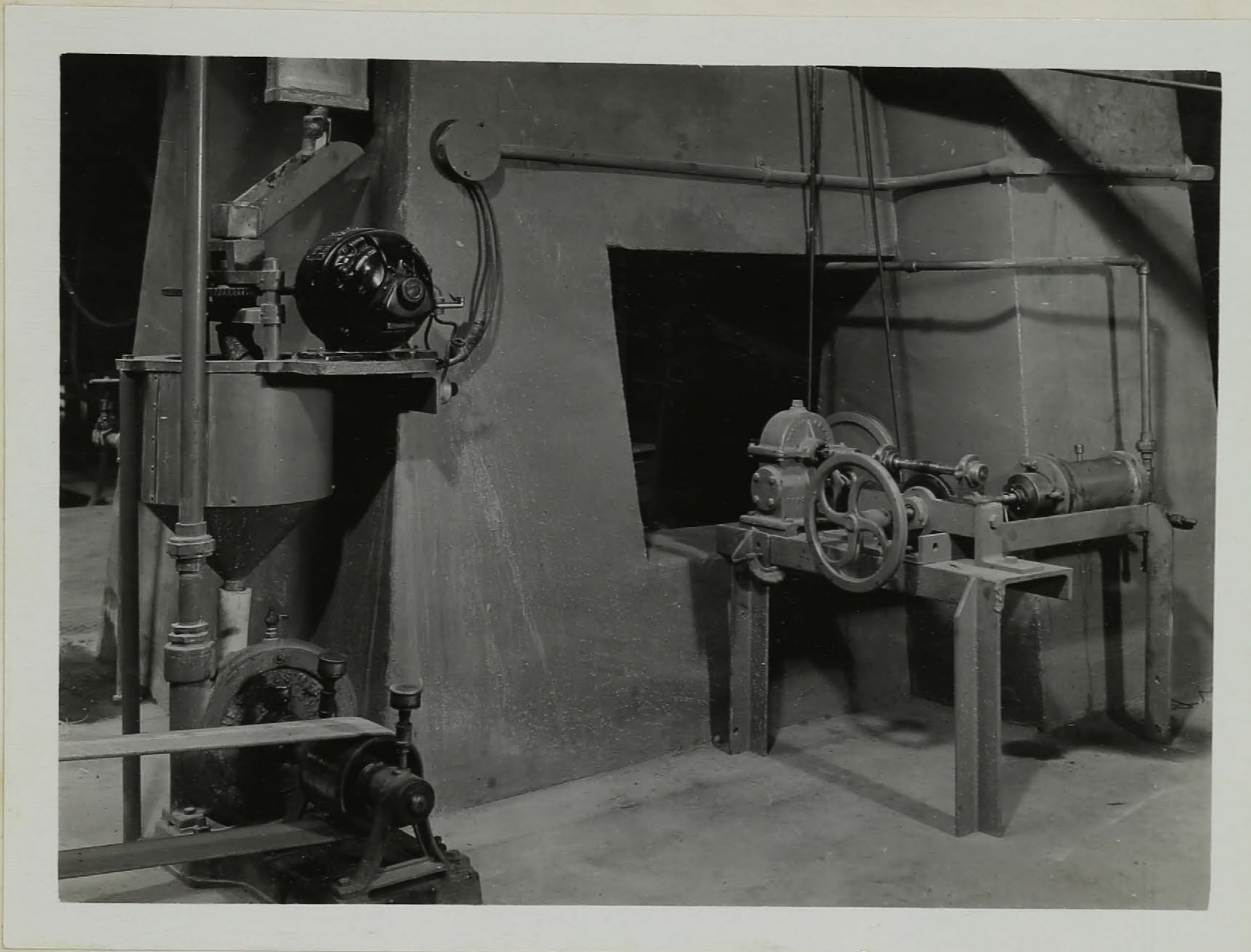
(2) Ammeter.

(3) At extreme right, mechanical revolution counter attached through Bell Brake to motor.

(b) BELL BRAKE.

Note the brake, band, lever arm and scale; also the fine screw adjustment for applying loads and the water spray inside the drum of the brake for cooling.

The Brake is connected directly to the motor, which does not show in the photograph.



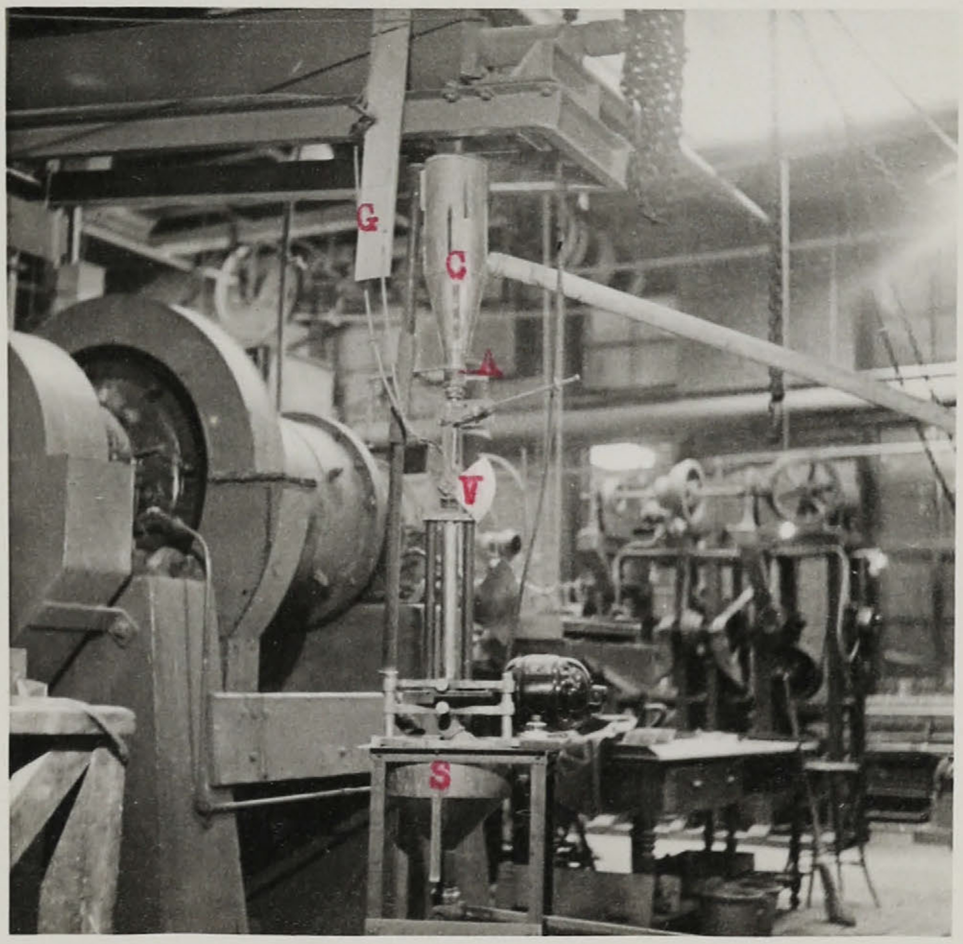
No. 5

Automatic Sampler
and
Centrifugal Pump.

Automatic Pressure
Grease Gun.

This sampler is at the discharge end of the mill.

The pump delivers the pulp to the classifier.



No. 6

CLASSIFIER OVERFLOW CONTROL TANK

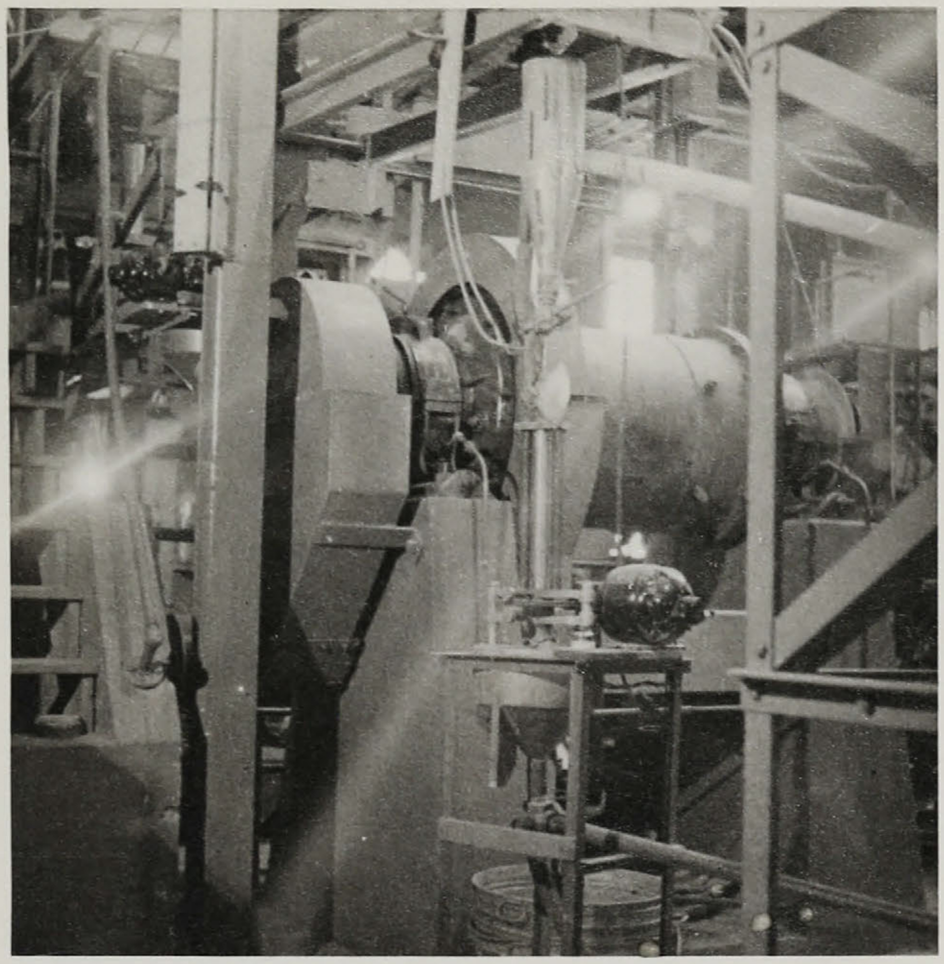
C - Control tank.

A - Air line.

V - Gate valve with screw control.

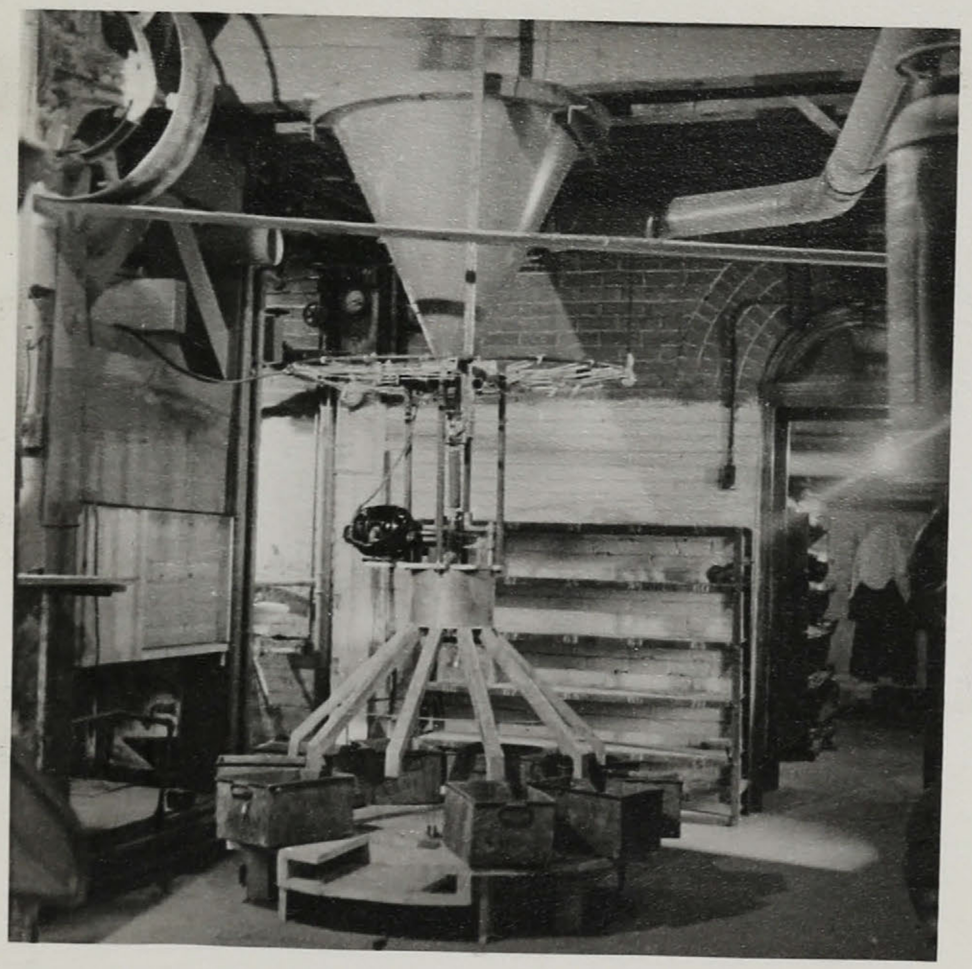
S - Sampler.

G - Water gauge.



No. 7

SHOWING RELATION OF OVERFLOW CONTROL TANK
TO MILL AND CLASSIFIER



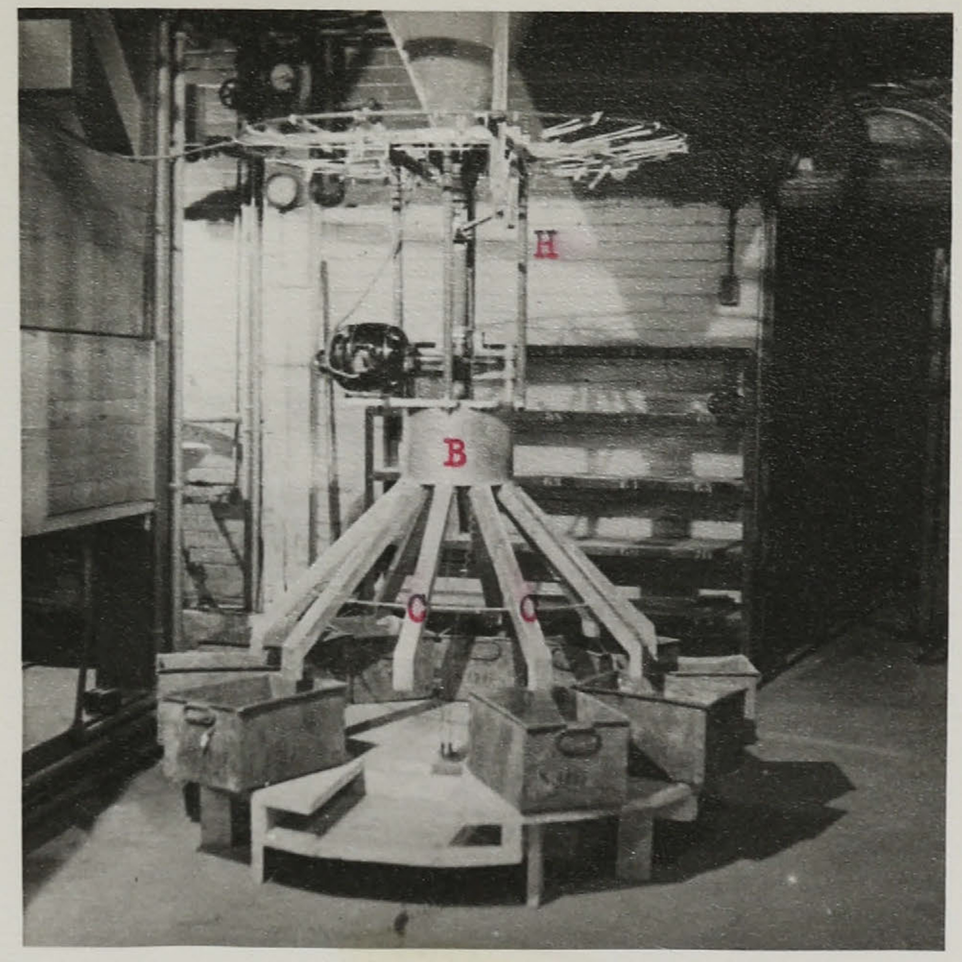
No. 8

ORE MIXER

General view

Note the circular framework at the bottom of the hopper for carrying a curtain to curtail "dusting"; also the space in the platform for carrying one box set on the scales.

The one foot vertical column, through which the ore is fed into the hopper does not show in the photograph.



No. 9

ORE MIXER

B - Ten compartments are built inside this circular box with the chutes - C - leading out from them. The spout revolves inside B delivering the ore into the compartments.

H - Handle for opening the gate valve to allow the ore to flow from the hopper to the spout.