CERTAIN PHASES
OF
FINE GRINDING

A STUDY OF CERTAIN PHASES OF FINE GRINDING

THESIS

submitted to the

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by

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The investigation described in this paper was jointly undertaken by Mr. N.H. Wadge, as the recipient of the Dr. James Douglas Fellowship in Mining Engineering, and the writer, as the recipient of the Sir William Dawson Fellowship in Mining Engineering. The work was carried out under the able direction of Professor J.W. Bell, Professor of Ore-Dressing, McGill University.

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Donald M. MacKay

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GENERAL INTRODUCTION

THE LAW OF CRUSHING AND ITS APPLICATION TO ORE-DRESSING

In 1867 P.R. Von Rittinger advanced his theory of crushing, which said, in effect, that "the energy required to produce successive steps in the reduction of rock is proportional to the new surface produced". This hypothesis was more or less universally accepted until 1885, when H. Stadler (2), initiated a lengthy dispute by his contention, based on Kick's Law, that "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". Stated more simply, this meant that the energy required for successive steps in reduction increases arithmetically, while, according to the Rittinger theory, it increases geometrically. It is obvious that Rittinger's theory calls for the expenditure of many times the power required by Kick's law to do the same work, and that, consequently, both can not be correct.

As a result of the Kick-vs.-Rittinger controversy, which lasted for some twenty years, it has been proved beyond doubt that Rittenger was right. But, as frequently occurs in disputes of this nature, various other facts have been brought to light which have opened up fresh fields of investigation.

Exponents of the Rittenger theory were hampered in their efforts to prove its validity as applied to rock-crushing by their inability to measure accurately the surface of particles in crushed material. In the coarser, or sieve sizes, this has not been such a serious obstacle for two reasons:

(1) It is possible, by careful screening with standard machines, to obtain reasonably accurate measurements of the surface of the screened material, and,

(2) It was realized by Bell (9), Gaudin (16), and others that the energy expended on sub-sieve particles represented a very large part of the total useful work done.

The need of a method for accurate surface measurement, especially of particles of sub-sieve size, finally led to a simultaneous solution of the problem. Martin (17), in England, and the United States Bureau of Mines (19), working independently and unknown to each other, evolved a dissolution method for the measurement of the surface of quartz particles. Both proved that the amount of surface produced in crushing quartz was directly proportional to the work expended. The writer considers the latter fact as being nothing more than corroboration of the published evidence of Gates(8), Bell (9), and others in support of Rittinger's theory.

With the law of crushing firmly established, and more or less accurate means of determining surface available, it has been a simple matter to compare crushing and grinding machines as to relative mechanical efficiency by the application of Rittenger's law. But no such figure as an absolute efficiency has ever been obtained by this method, mainly because of the fact that, as yet, no data has been available as to the amount of work represented by a definite amount of rock surface, or, stated differently, no method of measuring the actual energy expended in producing comminution, irrespective of all transmission and friction losses, has been devised.

A further difficulty presents itself in ore-dressing in that no method is known as yet for the measurement of surface in the sub-sieve sizes of particles of complex minerals, in which category most ores undoubtedly belong.

Because of the above considerations, investigations of recent years have been confined almost entirely to the field of fine grinding. They may be classified into the following groups:

(1) A search for some means of measuring absolute crushing or grinding efficiency, either by means of surface measurements or by thermal methods.

(2) A study of the various factors which affect the grinding efficiencies of modern machines, with the object of acquiring suitable data, which, when applied to commercial mills, will enable the operators to arrive at the most efficient grinding conditions.

The writer would place the work of Martin (17), Gross and Zimmerley (19), Fahrenwald et al. (24), and Edser under heading (1).

Examples of investigations of type (2), with one of which the present paper deals, are those of Taggart (11), Davis (12), Haultain and Dyer (13), Gaudin (16), Hardinge (18), Gow et al. (20), Fahrenwald and Lee (22), Gow and Guggenheim (25), and Gow et al. (29). The writer's opinion of the work done by these men is given in the next section of this introduction.

BALL MILLING

The comminution of ores in ball mills has been for many years in the past, and is to-day, practically standard procedure as a preparatory step to the recovery of the valuable minerals by flotation or cyanidation. Unfortunately it has also been, and still is, a highly expensive operation, relatively speaking. Modern methods of flotation have made possible a tremendous reduction in concentrating costs, but there has been no comparable reduction in grinding charges. The reason is fairly obvious, namely, that the ball mill is inherently a grossly inefficient machine. Recent investigations seem to indicate that no more than two or three percent of the total power supplied to a ball mill is actually expended in doing useful work; yet it remains the best machine in its field. Until a more efficient mechanism is developed, every effort should be directed toward making the best possible use of the existing one.

Granting that the ball mill as a type is an inefficient machine, the fact remains that the efficiency of any particular mill can be increased or reduced within fairly wide limits. The results of numerous tests reported in the literature bear testimony to this statement. A great many of the investigations described are of purely academic interest, nevertheless a substantial body of data has been compiled which has been of material assistance to milling men in making the most efficient use of their grinding equipment. It is hoped that the results of the investigation described in this paper will contribute, to some small extent, to the general fund of fine-grinding knowledge.

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A general review of previous experimental work on ball-milling problems reveals the fact that a large percentage of it is useless from a practical standpoint for one of the following reasons:

(1) The subject is of academic interest only.

(2) The laboratory equipment used in carrying out the investigation was either inadequate or of such limited dimensions that its performance could not be duplicated in commercial mills.

(3) No standard procedure was adopted in measuring the amount of useful work done per unit of power expended.

(4) There was not sufficiently accurate control of the various factors which affect the efficiency of a grinding machine, or else the effect of one factor was stressed unduly, to the exclusion of that of others equally as important.

(5) The conclusions drawn were inaccurate or were based upon insufficient evidence.

With the above considerations in mind, it was felt that a thorough investigation in the field of fine grinding was desirable, in order to clear away some of the existing confusion and point the way to a better understanding of the factors affecting grinding efficiency. In general, it was planned to extend the work over a number of years, stressing each factor in turn, and thus accumulating a complete list of data from which the most efficient operating conditions for ball mills could be determined.

(This method of attacking the problems of ball milling has been well demonstrated in the account of an exhaustive research, carried out by Gow, Guggenheim, Campbell and Coghill, published since this investigation was commenced. In their paper, entitled "Ball Mining", these authors have discussed the effects on power and grinding of a multitude of variables, which they divided into two groups, namely, set variables and induced ones. They carried out numerous experiments, with both laboratory and commercial equipment, in an endeavour to discover the influence exerted by the set variables on the induced ones, and the effect of both on the power and grinding. The results obtained were quite enlightening and helpful, although the practical value of some of the formulae, built upon the results of tests made with a 2-ft. laboratory ball mill, seems doubtful. Gow et al. contended that a 2-ft. mill gave a performance comparable to that of commercial mills; whether this be true or false, the 3-ft. mill used in the present investigation would be expected to give results which would more closely resemble those obtained in practice with larger ones.)

In accordance with the program outlined above, a grinding plant was installed in the mining laboratory during the summer of 1932, and the session 1932-33 was devoted almost entirely to studying the mechanical characteristics of the plant and equipping it with the necessary regulators and control apparatus. Special attention was directed to the elimination of mechanical losses in the ball mill and to the smoothing-out of irregularities in the power drawn by this machine. Other features also received considerable attention, as will be described later.

Only three actual grinding tests were completed during the 1932-33 session, the results of which were of little importance except as an indication of the performance that might be expected from the equipment with suitable adjustments.

In 1933-34 some mechanical changes were made in the grinding plant and several speed tests completed. The results of these tests seemed to indicate that a ball-mill speed of 39 r.p.m. gave the most efficient grinding. Both these tests and those of the previous session were carried out with a 3-ft. Marcy ball mill, equipped with a Marcy Quick-Discharge grid.

During the session 1934-35 the grinding tests were temporarily suspended while an investigation was carried out on a closely related phase of the grinding problem. This was an endeavour to develop an apparatus of a photoelectric nature which would make feasible the measurement of the surface of -200 mesh quartz. Such an apparatus seemed urgently required, in order that the work done in the grinding tests on particles of sub-sieve size could be accurately determined. While no very satisfactory results were obtained, many interesting facts concerning the characteristics of the apparatus were disclosed, and it is not improbable that its use will become practicable at some future date.

As the result of a conference between professors and graduate students of the Department of Mining, held in October, 1935, it was decided to resume the original grinding schedule during the session 1935-36. In addition to completing the required number of tests with the Marcy quick-discharge mill it was hoped that a duplicate set of tests could be completed using the same mill minus the grid, i.e. with free discharge. Such a procedure promised much in the way of comparative results, which could not fail to be of vital interest to both laboratory investigators and practical milling men alike, inasmuch as the question of whether or not discharge grids improve the grinding performance of ball mills has long been in dispute.

DESCRIPTION OF APPARATUS

Before entering upon a detailed description of its individual parts, a general survey of the grinding plant as a whole, and of the general procedure adopted, seems not to be amiss. In its present state, the plant represents the result of nearly four years of constant and painstaking improvement, throughout which time the guiding principle has been to duplicate as nearly as possible commercial plant practice and at the same time maintain laboratory accuracy of control. It was felt that only by so doing could the phenomena observed during experimental tests be properly interpreted and relied upon as the basis for useful conclusions possessing practical applications.

A study of the flow sheet (Plate 5), shows that in essential details the plant resembled fairly closely those in commercial practice. The bucket elevator, by means of which the mill discharge was carried to a sufficient height to enable it to run by gravity to the classifier, can not be considered standard equipment, but it saved space and in no way affected the grinding operation. Similarly, the constant-head overflow tank on the classifier is not found in commercial plants, but it did not affect either the rate or amount of overflow and consequently had no effect on the circulating load or the grinding performance. It was merely one of the refinements introduced to facilitate the accurate measurements previously mentioned, as will be explained in detail later. During all grinding tests the entire classifier overflow was caught in tubs and carefully weighed, in order to ascertain whether or not the mill was in balance before samples of mill discharge, classifier overflow and classifier sand-return were taken; this also was not commercial procedure but it is another illustration of the care exercised to maintain a high standard of accuracy in all observed or calculated data. Other examples of departures from standard practice will be given later, but it is safe to say here that none of them affected the ball mill efficiency any differently when the discharge grid was in use than when it was not.

DETAILED DESCRIPTION OF THE GRINDING PLANT

Power Supply, Control and Measurement:

The power used in the grinding tests was drawn from the University power house and entered the laboratory at approximately 220 volts. In order to insure a constant performance by the motor driving the ball mill, it was found necessary to maintain the applied voltage at exactly the same value throughout the tests, namely, 214 volts. This was accomplished by means of two variable resistances of 0.036 ohms each inserted in series in the incoming line. These were operated manually and continuously to suit the power fluctuations.

The power delivered to the motor was measured during all tests by a Sangamo integrating wattmeter, which was installed at the beginning of the session. It proved to be extremely accurate and dependable. Direct readings could be made to 0.01 K.W.H. and by interpolation to 0.002 K.W.H.

A D.C. voltmeter and an ammeter were placed in the motor circuit for sight readings to check the wattmeter. The voltmeter was watched continuously to see that the applied voltage to the motor was constant at 214 volts.

<u>Motor:</u>

The motor was designed and built by the English Electric Company. It is compound-wound, with a continuous rating of 30.6 amps., 220 volts, at 625 r.p.m. Its speed was controlled by two variable resistances in series, so constructed that a very fine speed adjustment was possible, ranging from 640 to 2000 r.p.m. The motor has a cooling fan attached to its shaft at one end and a Bell brake and revolution counter at the other.

<u>Ball Mill:</u>

A Marcy ball mill made by the Mine and Smelter Supply Co., Denver, Col., was used for all grinding tests. It is three feet long and two feet in diameter inside the liners, which are of the wave type. The mill is mounted on trunnions. A pulley on the motor, connected by a rubber belt to the main pulley on the ball mill, turns a pinion gear which in turn drives the annular gear on the mill.

The mill is equipped with a spiral feed scoop and a quick-discharge grid. The latter was removed to carry out free discharge tests.

The weight of the mill is carried by two trunnions which are mounted in babbit journal bearings kept constantly lubricated by grease from an automatic feeder. This grease feeder is a steel cylinder containing a piston, piston rod and the necessary packing. The piston rod is threaded and is forced into the cylinder by the rotation of a threaded wheel driven by a worm gear. The worm gear is operated by a speed reducer which in turn is driven by belting from a small pulley on the ball mill countershaft. The overall speed reduction is about 2000-1 and a cylinder of grease lasts about 60 hours of ball mill operating time.

Lead weights, attached to the main gear, served to counter-balance the weight of the feed scoop and thus eliminate large fluctuations in the power during each revolution of the mill.

A semicircular screen was placed beneath the discharge lip of the mill to remove pieces of balls and wood pulp, etc., from the discharge.

Bucket Elevator:

The mill discharge, mixed with a regulated amount of water, flowed by gravity to a boot from which it was lifted by a chain of buckets and dumped into a small cylindro-conical tank attached to the bucket-housing. This tank is about six feet above the level of the classifier to which the pulp flowed by gravity through a rubber hose attached to the bottom of the tank.

Classifier:

The classifier 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 pulp. On the up stroke it moves the return sand up the incline, eventually pushing it over the lip into a trough whence it is washed back, through an automatic sampler, into the feed box on the ball mill by the water supplied to the mill. The operation of the classifier is a combination of the Dorr and Akins principles.

The classifier overflow fell into a constant-head tank which eliminated most of the surging caused by the motion of the drag. From this tank the overflow ran through a pipe either into weighing tubs or to a Wilfley pump which elevated it to a large storage tank. The level of the overflow pulp in the constant-head tank could be adjusted at will by means of a calibrated valve at the bottom. Compressed air was introduced near the bottom of the tank to keep the pulp in mild agitation and thus prevent settling of the solids with consequent blocking of the discharge valve.

Rock Feeder:

Feed rock was dumped into a small hopper on the crushing floor whence it fell by gravity onto a conveyor belt. This belt is 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 conveyor belt delivers the feed to the feed box on the ball mill, where it is picked up by the scoop feeder and passes into the mill through the hollow trunnion.

This feeding mechanism is capable of giving feed rates varying from 0 to 600 lbs. per hour, and of maintaining any desired rate of feed for any length of time, provided the feed itself is of uniform composition.

Automatic Pulp Samplers:

These were three in number, located as follows:

(1) In the mill discharge circuit.

(2) In the classifier return circuit.

(3) In the classifier overflow circuit.

Each sampler consists of a discharge tube, sloping at an angle of 45°, which is rotated by an electric motor through a worm gear drive. In the circular path made by the lower end of the discharge pipe is placed a radial cutter whose opening takes a certain percentage of the total flow and delivers it to a sample bottle placed beneath the sampler. The sample so obtained is about 1/40 of the total flow.

Water Supply:

The main water supply used in the tests was a large constant-head tank situated well above the grinding plant. From this tank the water is fed through brass piping to the feed box of the mill via the classifier return sand trough and to the automatic sampler in the mill discharge circuit. The flow of water was very accurately controlled during tests by means of calibrated valves in each pipe line.

ACCESSORY EQUIPMENT

The accessory equipment includes:

(1) Electric revolution counters, recording feed-belt travel, ball mill revolutions and classifier strokes.

(2) Vacuum filters.

(3) Weigh scales.

(4) Sample tubs.

(5) Sample bottles.

(6) Bell screening machine equipped with Tyler standard screens.

(7) Bell brake attached to the ball mill motor.

(8) Bell feed-rock mixing machine.

The Bell Brake:

In order to determine the output of the ball mill motor for any input, its armature shaft was permanently connected through a flexible coupling to a Bell brake. The brake consists of the usual drum mounted on a steel shaft running in ball bearings. The braking load is applied by lapping an oil-soaked canvas belt on the drum. One end of the belt is attached to a system of levers which records the load on a balance. The other passes around a portion of the brake drum between the drum and a roller, which can be shifted to any position about the rim of the drum. This roller keeps the belt in contact with the drum over any desired arc of circumference. A hanging lead weight (approximately 11 lbs.) keeps the belt taut.

The roller which controls the belt lap is operated by means of a worm gear so that very small changes in load can be made. In using the brake the tare of the belt and lead weight is subtracted from the load recorded on the balance.

The brake drum is cooled by a continuous stream of water from a constant-level tank, which is directed inside the drum, flows to the edges, around the periphery and is scooped out by a pipe, adjusted close to the inside surface of the drum, and run to waste.

This brake has the advantages over others of its type of extreme sensitivity and smoothness of load control coupled with constant performance at any given load.

<u>The Bell Feed-Rock Mixer:</u>

This apparatus was used in the preparation of all feed rock to mix the latter so thoroughly that there would be no appreciable variation in the character of the feed for any one test. The importance of insuring such uniformity in tests of a comparative nature is obvious.

The fundamental principle involved in the use of this machine is that of cutting. Feed rock contained in a large cone-shaped tank runs down through a vertical pipe, equipped with a slide valve, into a revolving pipe inclined at approximately 45^{o}, by means of which it is distributed into the mouths of ten square chutes placed close together around the circumference of the circle described by the lower end of the revolving pipe. These chutes direct the rock into boxes placed under them on a revolving platform; theoretically each box receives, therefore, one-tenth of the total flow for any given period. Actually it is found that all boxes do not receive exactly the same amount, due to slight variations in the shape and size of the chute mouths. To correct this condition, the positions of the boxes are changed at regular intervals by rotating the platform carrying them. Each box moves around one place at each change, and occupies a position beneath each of the ten chutes for equal intervals of time. The result is that each box receives the same amount of feed over the total period, or would receive it providing the feed itself was flowing at a uniform rate. This is really the crux of the whole operation; i.e. when each box receives exactly the same amount of feed for any given time of flow, the feed may be considered to be uniformly and completely mixed.

The revolving-pipe distributor is driven by a quarter-horse-power, constant-speed, D.-C. electric motor. The platform is moved by hand, although it might be quite feasible to arrange some revolving mechanism using the distributor motor as a source of power.

EXPERIMENTAL PROCEDURE

A. - Preparation of Feed Rock:

The ball-mill feed used throughout this investigation was a local quartzite which was delivered to the campus in carload lots. Before being piled inside the laboratory the pieces were broken with sledge hammers to a size suitable for the gyratory crusher, i.e. to approximately 6 in. maximum dimension. The crushing flow sheet is given in Plate 6.

At the beginning of the 1935-36 session approximately 5 tons of feed rock, previously crushed, screened and bagged, were on hand in the laboratory. Since expectations were that at least 20 tons would be required to complete a sufficient number of grinding tests, approximately 17 tons of rock were prepared according to the flow sheet given in Plate 6 and piled, along with the original 5 tons, on the crushing floor.

The next step was to run the entire lot once through the Bell mixer. This machine has ten discharge spouts (see photograph No. 1) and the bags, as they were refilled from these spouts, were taken off in the same order each time and piled on the crushing floor in rows of ten according to a predetermined scheme. The following plan will serve to illustrate the method adopted:

Bag No.

N

W — E

1	2	3	4	5	6	7	8	9	10
10	1	2	3	4	5	6	7	8	9
9	10	1	2	3	4	5	6	7	8
8	9	10	1	2	3	4	5	6	7
7	8	9	10	1	2	3	4	5	6
6	7	8	9	10	1	2	3	4	5
5	6	7	8	9	10	1	2	3	4
4	5	6	7	8	9	10	1	2	3
3	4	5	6	7	8	9	10	1	2
2	3	4	5	6	7	8	9	10	1

S

The revolving platform was not used during this preliminary mixing operation because the bag hangers interfered with its rotation. To regulate the weight of rock contained in each bag, one of them was placed on a scales whose beam was connected to an electric-bell circuit in such a manner that when the beam rose a contact was made and the bell rung. The beam was set to balance when a load of 51 lbs. was placed on the scales; allowing 1 lb. for the weight of a bag, this meant that each bag when filled contained approximately 50 lbs. of rock.

Referring to the table above it will be readily seen, therefore, that by taking any N - S row of bags, a fairly representative sample of the whole amount of rock could be obtained, which would weigh approximately 500 lbs. In order to save space, the bags were arranged in two lots, identical in plan with that shown in the table, but in four tiers. Thus, a representative sample could be obtained, by taking any quadruple N- S row, which would weigh approximately two tons. This happened to be the greatest amount which could be readily handled during the mixing operation proper, and usually proved to be quite sufficient for two ball-mill tests.

By means of numerous tedious trials with the mixing machine, it had been discovered that the maximum rate of flow for -$\frac{1}{4}$- in. feed rock, when of uniform mix, was 1850 lbs. per hour. On this basis, it was a simple matter to calculate the time of flow necessary to give ten equal portions of any desired weight (in this case 40 lbs.), and from this to determine the correct time interval for the rotation of the boxes supplied to receive them.

Considering our concrete case, the calculations were as follows:

Ten boxes @ 40 lbs. rock each = 400 lbs.

Total time of flow per ten boxes, mins. $\frac{400 \times 60}{1850}$

Length of interval between changes in position

of boxes, secs. $= \frac{(400 \times 60 \times 60)}{1850 \times 10} = 77.82$

$= 1$ min. 18 secs.

Each 2000-lb. lot of feed rock was run through the mixer until the rate of flow became constant at 1850 lbs. per hour. When this condition was reached, every box weighed slightly more than 40 lbs. net, since the total time of flow per ten boxes was taken as 13.0 instead of 12.97 mins.

B. - Motor Brake Tests:

These were preliminary tests which were carried out with a threefold purpose:

(a) To check the performance and accuracy of the newly installed wattmeter.

(b) To find the particular settings of the controlling rheostats which would give ball mill speeds of 39, 43, 47 and 50 r.p.m.

(c) To supply data from which curves could be drawn for each pertinent motor speed by plotting K.W.H. input vs. H.P. output.

In carrying out the brake tests, the following procedure was adopted:

1. It being known from the results of previous tests that the ball mill speed was equal to

motor r.p.m. x 0.0605

it was a simple matter to determine the correct motor speed for each of the desired ball-mill speeds. From this point it was a case of trial and error to find the settings of the rheostats which would give the correct motor speeds, previous work by other investigators being of some help as a guide.

2. With the four useful motor speeds determined, brake tests were carried out at each speed to find the H.P. output for a given K.W.H. input over a range in motor amperage of from 18 to 24 amps. It was known that the amperage drawn by the motor would not be likely to exceed the higher figure. The Bell brake was used for all brake tests.

3. From the recorded observations of K.W.H. input, net brake load, etc., the efficiency of the motor was determined at the various speeds and over the desired amperage range at each speed. Graphs were drawn for each speed by plotting H.P. output vs. K.W.H. input. (See Plates 1 - 4. The "Set" refers to the settings of the two rheostats which control the motor speed.)

C. - Calibration of Water Valves:

In all ball-milling investigations, the liquid : solid ratio of the pulp in the mill has been found to be one of the most important factors governing grinding efficiency. The necessity, therefore, of maintaining accurate control of the amount of water entering the mill can readily be appreciated. Furthermore, since the efficacy of a classifier to separate finished products from unfinished ones, in the circulating load, depends to a large extent upon the liquid : solid ratio of the classifier feed, the amount of water added to the mill discharge before it reaches the classifier must also be rigidly controlled. In the present investigation, where everything depended upon exact duplication of mill-conditions, the considerations outlined above assumed double importance.

As has been previously mentioned, the main water supply for the grinding plant in the mining laboratory is a large constant-level iron tank situated well above the mill and other equipment. From this tank, water is fed to the ball mill and to the mill discharge sampler through brass pipes, one to the mill and two to the discharge. The mouths of these pipes are covered by removable screens of fine mesh which prevent rust or other foreign matter from entering them and clogging the valves. Small tubes, tapped into the pipes, serve to draw off entrapped air along with a small stream of water, so that the amount of water carried by each pipe to its controlling valve is unvarying.

For the purposes of the present investigation, it was deemed necessary to calibrate the water valves as follows:

1. Valve No. 1 (ball mill),
   for flows ranging from 135 - 265 lbs. /hr.
2. Valve No. 2 (classifier),
   for flows ranging from 175 - 235 lbs. /hr.
3. Valve No. 3 (classifier),
   for flows ranging from 470 - 800 lbs. /hr.

The valves are of a special design which permits the regulation of the flow of water through them to within 1 lb. /hr. In view of the total amounts used per hour from each pipe during the tests, this deviation never amounted to more than one percent of the calculated flow.

A compilation of the data acquired from the calibration tests is given in Table 1.

D. - Test Procedure:

The sequence of operations which was carefully adhered to throughout all grinding tests was as follows:

1. The rate of feed to the ball mill, lbs. per hr., the liquid : solid ratio of the pulp in the mill

and the ball-mill speed were determined, and the feed conveyor, water valves and motor rheostats adjusted accordingly.

2. After an inspection of the mill, classifier, etc., the water to the mill discharge was turned on and the bucket elevator started.

3. As soon as it was clear that no blockages had occurred between elevator and classifier while the plant was idle, the feed conveyor, ball mill, ball-mill water flow and classifier were started simultaneously and the recording of various observations commenced. Those which were recorded continuously from start to finish of the tests were as follows:

(a) The feed rate, determined by timing the consumption of every pair of 40-lb. boxes of feed rock. By this means the actual feed rate was measured and a check on the performance of the feed conveyor was provided as well.

(b) The ball-mill speed, r.p.m.

(c) The classifier speed, strokes per min.

(d) The feed-conveyor travel.

(e) The motor speed, r.p.m.

(f) The applied voltage to, and the amperage drawn by, the motor.

(g) The power supplied to the motor, K.W.H. per hour.

Except for the applied voltage reading, the observations from (b) to (g) inclusive were recorded every half-hour. The voltmeter was watched continuously and the voltage regulated so that it was constant at 214.

Suitable forms were provided which facilitated the recording of all observations.

4. Approximately 1 hr. after the beginning of the test, tub-sampling of the classifier overflow was commenced. This was continued until two or more successive lots of four tubs each weighed approximately the same amount, at which time the plant could be considered to be in balance. Each tub contained the overflow for a period of two, three or four minutes, depending on the tonnage ground per hour.

Usually, the interval between the time a test was commenced and that when the mill gave a constant performance was about three hours.

5. With the mill in balance samples were taken, by means of the automatic samplers, of the classifier overflow, classifier return sand and the mill discharge. These samples were taken over a period of from 16 - 30 mins. each, depending, again, upon the tonnage being handled by the mill per hour. The classifier overflow was always sampled first, either one or two samples being taken, and then the return sand and the mill dis-

charge were sampled simultaneously, one sample being taken of each. The reason for this procedure was that it avoided any danger of a variation in the classifier feed, while the overflow sample was being taken, which might affect the amount or composition of the latter. The return sand was not subject to a comparable error, since its total tonnage was, relatively, very small.

After removing, with a vacuum pump, the air entrapped in the pulp of the samples, the latter were weighed and by means of various calculations, which will be described later, their specific gravities and L : S ratios and the tonnages per hour represented by them were determined. The samples were then set aside for filtering, drying, screening, etc. This completed the test proper.

The usual procedure followed was to run two tests in one day, unless the tonnages were too large to permit of preparing a sufficient amount of feed in advance, or a breakdown necessitating lengthy repairs occurred. Whenever one test followed another on the same day, the necessary changes in operating conditions for the new test were effected within a few minutes, without stopping any of the machinery. It was always found that the mill took much less time to reach a balance in the second of two such tests, because the circulating load and the volume of pulp in the mill were already built up to approximately the correct amounts.

TABLES

TABLE 1.

Valve No. 1			Valve No. 3		
Setting	Rate of Flow, lbs. per hr.	Diff.	Setting	Rate of Flow, lbs. per hr.	Diff.
3.3	135.52	-	5.7	463.80	-
3.4	146.22	10.70	5.8	484.28	20.48
3.5	154.73	8.51	5.9	501.55	17.27
3.6	164.08	9.35	6.0	520.60	19.05
3.7	171.36	7.28	6.1	536.90	16.30
3.8	181.02	9.66	6.2	555.30	18.40
3.9	189.00	7.98	6.3	570.60	15.30
4.0	197.07	8.07	6.4	586.90	16.30
4.1	206.79	9.72	6.5	602.00	15.10
4.2	214.27	7.48	6.6	620.00	18.00
4.3	223.55	9.28	6.7	637.08	17.08
4.4	231.38	7.83	6.8	649.81	12.73
4.5	239.35	7.97	6.9	666.00	16.19
4.6	248.43	9.08	7.0	681.00	15.00
4.7	256.50	8.07	7.1	698.85	17.85
4.8	264.35	7.85	7.2	714.92	16.07
			7.3	728.85	13.93
Valve No. 2			7.4	742.95	14.10
3.0	177.54	-	7.5	758.85	15.90
3.1	197.82	20.28	7.6	770.10	11.25
3.2	218.04	20.22	7.7	787.95	17.85
3.3	238.23	20.19			

WATER-VALVE CALIBRATIONS.

Dept. of Mining Engineering,
McGill University

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REPORT OF SCREEN ANALYSIS

TABLE 2

Ball Mill Feed TEST No. ....

SAMPLE No.		1		2					
WASHING TEST		Grams		Grams		Grams		Grams	
Total Wt. Taken		120.12		188.26					
+ 200 Mesh									
− 200 Mesh									
COMPLETE ANALYSIS		Weights on or Between Screens		Weights on or Between Screens		Weights on or Between Screens		Weights on or Between Screens	
Opening m.m.	Mesh	Grm.	%	Grm.	%	Grm.	%	Grm.	%
									Aver.
4.699	+ 4	2.22	1.85	6.07	3.22				2.5
3.327	+ 6	22.64	18.83	42.26	22.41				20.6
2.362	+ 8	21.35	17.79	31.82	16.91				17.4
1.651	+ 10	24.46	20.35	33.32	17.68				19.0
1.168	+ 14	10.50	8.72	16.85	8.95				8.8
0.833	+ 20	7.95	6.61	12.37	6.58				6.6
0.589	+ 28	7.23	6.02	10.04	5.33				5.7
0.417	+ 35	4.43	3.68	6.62	3.52				3.6
0.295	+ 48	4.83	4.01	7.36	3.91				4.0
0.208	+ 65	5.22	4.35	7.57	4.02				4.2
0.147	+ 100	5.83	4.85	8.80	4.68				4.8
0.104	+ 150	1.87	1.55	2.98	1.58				1.6
0.074	+ 200	0.58	0.48	0.93	0.49				0.5
(Sand)	− 200	0.37	0.31	0.50	0.27				0.3
(Slime)	− 200								
TOTAL		119.48	99.40	187.49	99.55				99.6

Form Mng. 5. 1936 1000 copies.

Mill Test No. 23 Date **Jan. 14** 19**36** Page

CRUSHING MEDIA.

Lbs. **1.75** Inch
Lbs. **1.50** Inch
Lbs. Inch
Lbs. Inch

Total **1144** Lbs. -------- **Balls.**

Mill Volume------ **10.8** Cu. Ft.

Occupy **36.4** Percent Mill Vol.

MILL.

Pulp **30.7** Percent Water.
69.3 Percent Solids.

Speed -------- **42.7** R.P.M.
Critical Speed **56.7** R.P.M.
Percent of Crit. Speed **75.2**

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

CLASSIFIER.

Slope------- **1.26** Inches per Foot.
Strokes ---- **24.3** Per Minute.
Return Sand **45.0** Dry Lbs. per Hr.
+
Water ------ **27.0** Lbs. per Hour.

Overflow
Solids--- **293** Dry Lbs. per Hr.
Water---- **587** Pounds per Hour.

Liquid-Solid Ratio **1.98** : 1

BELT FEEDER.

Vernier Setting -------- **31.0**
Feed-Dry Pounds per Hr.- **293.0**
Strokes per minute------ **39.1**
Pounds per Stroke------- **1.25**

TIME.

Duration of Test **6.0** Hours.
Preparat. Period **4.7** Hours.
Sampling Period **1.3** Hours.

WATER

		At Start.		At End.
No.1 Cock (Feed Water) Dial Setting-------	**3.3**	Lbs. per Hr.	**135.5**	Lbs. per Hr.
No.2 Cock (To Classifier) Dial Setting-------	**-**	Lbs. per Hr.	**-**	Lbs. per Hr.
No.3 Cock (to Mill Disch.) Dial Setting-------	**5.7**	Lbs. per Hr.	**463.8**	Lbs. per Hr.
		Total per Hr.	**599**	Total per Hr.

POWER.

214 Volts. **20.8** Amps. Wattmeter **4.58** KWH per Hr.

Input to Motor **6.12** H.P. Motor Efficiency **78.6** Percent.

Power Delivered to Mill -------------------- **4.81** H.P.
Power lost in Mill Bearings, Drive Gear, Etc. **1.08** H.P.
Power absorbed in Crushing ----------------- **3.73** H.P.

Mill Test No. 23 cont'd. Date Jan. 14 1936 Page

MESH	RET'N SAND % WT.	MILL DISCH. % WT.	MILL FEED % WT.	MILL FEED SURFACE. S. CM÷100	SQ. CM. PER GRAM / 100	CLASSIF. O'FLOW SURFACE S.CM÷100	CLASS. O'FLOW % WT.
-3 +4			2.5	0.9	0.35		
+6			20.6	9.3	0.45		
+8			17.4	8.7	0.50		
+10			19.0	11.4	0.60		
+14	0.1	0.1	8.8	6.2	0.70		
+20	0.1	0.1	6.6	5.8	0.90		
+28	0.6	0.1	5.7	6.0	1.05		
+35	1.85	0.3	3.6	5.0	1.40		
+48	6.9	0.8	4.0	7.0	1.75		
+65	13.6	2.5	4.2	9.6	2.35	1.4	0.6
+100	28.4	8.4	4.8	15.1	3.15	17.0	5.4
+150	17.4	11.0	1.6	6.8	4.25	43.8	10.3
+200	12.0	15.1	0.5	2.8	5.50	85.3	15.5
-200	18.8	61.6	0.3		75.00	5110.0	68.2
TOTAL	99.75	100.0	99.6	100.0	SQ. CM. PER GRAM	5257.5	100.0

CLASSIFIER OVERFLOW (FINISHED PROD.)	5258	SQ.CM. PER GRAM
MILL FEED	100	SQ.CM. PER GRAM
NEW SURFACE	5158	SQ.CM. PER GRAM

DRY PRODUCTS	TONS PER 24 HOURS	POUNDS PER HOUR	GRAMS PER SECOND	NEW SURFACE SQUARE CENTIMETRES PER SECOND
MILL DISCHARGE	4.05	338	42.7	
RETURN SAND	0.54	45	5.7	
CLASS. OVERFLOW	3.51	293	37.0	194800

GROSS POWER DELIVERED TO MILL	2520	FT. POUNDS PER SEC.
NET POWER ABSORBED IN CRUSHING	2050	FT. POUNDS PER SEC.

NOTE:- 6.45 SQ.CM. = 1 SQ.INCH

EFFICIENCY	NEW SURFACE SQUARE CENTIMETRES	NEW SURFACE SQUARE INCHES
GROSS - 1 FOOT-POUND PRODUCED	76.6	
NET - 1 FOOT-POUND PRODUCED	95.0	14.7

Mill Test No. 24 Date Jan. 14 1936 Page

CRUSHING MEDIA.

Lbs. 1.75 Inch
Lbs. 1.50 Inch
Lbs. Inch
Lbs. Inch

Total 1139 Lbs. -------- Balls.

Mill Volume------ 10.8 Cu. Ft.

Occupy 36.2 Percent Mill Vol.

MILL.

Pulp 30.6 Percent Water.
69.4 Percent Solids.

Speed -------- 46.9 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 82.8

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

CLASSIFIER.

Slope------- 1.26 Inches per Foot.
Strokes ----24.3 Per Minute.
Return Sand-33.8 Dry Lbs. per Hr.
+
Water ------16.0 Lbs. per Hour.

Overflow
Solids--- 295 Dry Lbs. per Hr.
Water---- 593 Pounds per Hour.

Liquid-Solid Ratio 1.99 : 1

BELT FEEDER.

Vernier Setting -------- 31.0
Feed-Dry Pounds per Hr.-295.0
Strokes per minute------ 39.3
Pounds per Stroke------- 1.25

TIME.

Duration of Test 3.5 Hours.
Preparat. Period 2.0 Hours.
Sampling Period 1.5 Hours.

WATER

	Dial Setting	At Start.	At End.
No.1 Cock (Feed Water) Dial Setting-------	3.3	Lbs. per Hr. 135.5	Lbs. per Hr.
No.2 Cock (To Classifier) Dial Setting-------	-	Lbs. per Hr. -	Lbs. per Hr.
No.3 Cock (to Mill Disch.) Dial Setting-------	5.7	Lbs. per Hr. 463.8	Lbs. per Hr.
		Total per Hr. 599	Total per Hr.

POWER.

214 Volts. 22.6 Amps. Wattmeter 4.99 KWH per Hr.

Input to Motor 6.66 H.P. Motor Efficiency 79.3 Percent.

Power Delivered to Mill -------------------- 5.28 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 1.17 H.P.
Power absorbed in Crushing ----------------- 4.11 H.P.

Mill Test No. 24 cont'd. Date Jan. 14 1936 Page

MESH	RET'N SAND % WT.	MILL DISCH. % WT.	MILL FEED % WT.	MILL FEED SURFACE. S. CM÷100	SQ. CM. PER GRAM / 100	CLASSIF. O'FLOW SURFACE S.CM÷100	CLASS. O'FLOW % WT.
-3 +4					0.35		
+6				As in	0.45		
+8				Test 23.	0.50		
+10					0.60		
+14					0.70		
+20	0.2	0.1			0.90		
+28	0.9	0.2			1.05		
+35	1.9	0.2			1.40		
+48	6.7	0.8			1.75		
+65	13.8	2.3			2.35	1.2	0.5
+100	28.8	7.7			3.15	16.7	5.3
+150	17.0	10.6			4.25	43.4	10.2
+200	11.5	13.9			5.50	80.4	14.6
-200	19.2	64.2			77.50	5370.0	69.4
TOTAL	100.0	100.0		100.0	SQ. CM. PER GRAM	5511.7	100.0

CLASSIFIER OVERFLOW (FINISHED PROD.)	5512	SQ.CM. PER GRAM
MILL FEED	100	SQ.CM. PER GRAM
NEW SURFACE	5412	SQ.CM. PER GRAM

DRY PRODUCTS	TONS PER 24 HOURS	POUNDS PER HOUR	GRAMS PER SECOND	NEW SURFACE SQUARE CENTIMETRES PER SECOND
MILL DISCHARGE	3.94	329	41.5	
RETURN SAND	0.41	34	4.3	
CLASS.OVERFLOW	3.53	295	37.2	201500

GROSS POWER DELIVERED TO MILL	2905	FT.POUNDS PER SEC.
NET POWER ABSORBED IN CRUSHING	2260	FT.POUNDS PER SEC.

NOTE:- 6.45 SQ.CM. = 1 SQ.INCH	NEW SURFACE	
EFFICIENCY	SQUARE CENTIMETRES	SQUARE INCHES
GROSS - 1 FOOT-POUND PRODUCED	79.3	
NET - 1 FOOT-POUND PRODUCED	89.1	13.8

Mill Test No. 25 Date Jan. 22 1936 Page

CRUSHING MEDIA.

Lbs. 1¾ Inch
Lbs. 1½ Inch
Lbs. Inch
Lbs. Inch

Total 1136 Lbs. --------- Balls

Mill Volume------ 10.8 Cu. Ft.

Occupy 36.1 Percent Mill Vol.

MILL.

Pulp 30.3 Percent Water.
69.7 Percent Solids.

Speed -------- 39.8 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 70.2

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

CLASSIFIER.

Slope------- 1.26 Inches per Foot.
Strokes ----24.6 Per Minute.
Return Sand-67.0 Dry Lbs. per Hr.
+
Water ------31.0 Lbs. per Hour.

Overflow
Solids--- 300 Dry Lbs. per Hr.
Water---- 592 Pounds per Hour.

Liquid-Solid Ratio 1.98 : 1

BELT FEEDER.

Vernier Setting -------- 31.0
Feed-Dry Pounds per Hr.-300.0
Strokes per minute------ 39.5
Pounds per Stroke------- 1.27

TIME.

Duration of Test 4.2 Hours.
Preparat. Period 3.0 Hours.
Sampling Period 1.2 Hours.

WATER

		At Start.	At End.
No.1 Cock (Feed Water) Dial Setting-------	3.3	Lbs. per Hr. 135.5	Lbs. per Hr.
No.2 Cock (To Classifier) Dial Setting-------	-	Lbs. per Hr. -	Lbs. per Hr.
No.3 Cock (to Mill Disch.) Dial Setting-------	5.7	Lbs. per Hr. 463.8	Lbs. per Hr.
		Total per Hr. 599	Total per Hr.

POWER.

214 Volts. 18.55 Amps. Wattmeter 4.16 KWH per Hr.

Input to Motor 5.54 H.P. Motor Efficiency 77.7 Percent.

Power Delivered to Mill -------------------- 4.30 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 1.00 H.P.
Power absorbed in Crushing ------------------ 3.30 H.P.

Mill Test No. 25 cont'd. Date Jan. 22 1936 Page

MESH	RET'N SAND % WT.	MILL DISCH. % WT.	MILL FEED % WT.	MILL FEED SURFACE. S. CM÷100	SQ. CM. PER GRAM / 100	CLASSIF. O'FLOW SURFACE S.CM÷100	CLASS. O'FLOW % WT.
-3 +4					0.35		
+6				As in	0.45		
+8				Test 23	0.50		
+10					0.60		
+14	0.1				0.70		
+20	0.1				0.90		
+28	0.8	0.3			1.05		
+35	1.6	0.3			1.40		
+48	5.4	1.0			1.75		
+65	12.2	2.7			2.35	1.4	0.6
+100	28.1	9.0			3.15	17.9	5.7
+150	18.9	11.8			4.25	47.2	11.1
+200	12.8	15.2			5.50	77.0	14.0
-200	20.0	59.7			68.50	4705.0	68.6
TOTAL	100.0	100.0		100.0	SQ. CM. PER GRAM	4848.5	100.0

CLASSIFIER OVERFLOW (FINISHED PROD.)	4849	SQ.CM. PER GRAM
MILL FEED	100	SQ.CM. PER GRAM
NEW SURFACE	4749	SQ.CM. PER GRAM

DRY PRODUCTS	TONS PER 24 HOURS	POUNDS PER HOUR	GRAMS PER SECOND	NEW SURFACE SQUARE CENTIMETRES PER SECOND
MILL DISCHARGE	4.40	367	46.3	
RETURN SAND	0.80	67	8.5	
CLASS.OVERFLOW	3.60	300	37.8	179300

GROSS POWER DELIVERED TO MILL	2365	FT.POUNDS PER SEC.
NET POWER ABSORBED IN CRUSHING	1815	FT.POUNDS PER SEC.

NOTE:- 6.45 SQ.CM. = 1 SQ.INCH	NEW SURFACE	
EFFICIENCY	SQUARE CENTIMETRES	SQUARE INCHES
GROSS - 1 FOOT-POUND PRODUCED	75.9	
NET - 1 FOOT-POUND PRODUCED	98.7	15.3

Mill Test No. 26 Date Jan. 22 1936 Page

CRUSHING MEDIA.

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

Total 1131 Lbs. -------- Balls

Mill Volume------ 10.8 Cu. Ft.

Occupy 36.0 Percent Mill Vol.

MILL.

Pulp 30.3 Percent Water.
69.7 Percent Solids.

Speed -------- 50.6 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 89.2

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

CLASSIFIER.

Slope------- 1.26 Inches per Foot.
Strokes ----25.0 Per Minute.
Return Sand-50.0 Dry Lbs. per Hr.
+
Water ------23.0 Lbs. per Hour.

Overflow
Solids--- 300 Dry Lbs. per Hr.
Water---- 590 Pounds per Hour.

Liquid-Solid Ratio 1.986 : 1

BELT FEEDER.

Vernier Setting -------- 31.0
Feed-Dry Pounds per Hr.-300.0
Strokes per minute------ 39.65
Pounds per Stroke------- 1.26

TIME.

Duration of Test 5.0 Hours.
Preparat. Period 4.0 Hours.
Sampling Period 1.0 Hours.

WATER

	At Start.	At End.
No.1 Cock (Feed Water)		
Dial Setting-------	3.3 Lbs. per Hr.	135.5 Lbs. per Hr.
No.2 Cock (To Classifier)		
Dial Setting-------	- Lbs. per Hr.	- Lbs. per Hr.
No.3 Cock (to Mill Disch.)		
Dial Setting-------	5.7 Lbs. per Hr.	463.8 Lbs. per Hr.
	Total per Hr.	599 Total per Hr.

POWER.

214 Volts. 23.9 Amps. Wattmeter 5.34 KWH per Hr.

Input to Motor 7.13 H.P. Motor Efficiency 79.0 Percent.

Power Delivered to Mill -------------------- 5.63 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 1.23 H.P.
Power absorbed in Crushing ----------------- 4.40 H.P.

Mill Test No. 26 cont'd. Date Jan. 22 1936 Page

MESH	RET'N SAND % WT.	MILL DISCH. % WT.	MILL FEED % WT.	MILL FEED SURFACE. S. CM÷100	SQ. CM. PER GRAM / 100	CLASSIF. O'FLOW SURFACE S.CM÷100	CLASS. O'FLOW % WT.
-3 +4					0.35		
+6				As in	0.45		
+8				Test 23	0.50		
+10					0.60		
+14					0.70		
+20					0.90		
+28	1.0	0.3			1.05		
+35	1.8	0.2			1.40		
+48	6.6	0.8			1.75		
+65	14.4	2.3			2.35	1.2	0.5
+100	28.3	7.6			3.15	15.1	4.8
+150	16.7	10.2			4.25	40.4	9.5
+200	11.5	13.6			5.50	69.9	12.7
-200	19.7	65.0			76.5	5540.0	72.5
TOTAL	100.0	100.0		100.0	SQ. CM. PER GRAM	5666.6	100.0

CLASSIFIER OVERFLOW (FINISHED PROD.)	5667	SQ.CM. PER GRAM
MILL FEED	100	SQ.CM. PER GRAM
NEW SURFACE	5567	SQ.CM. PER GRAM

DRY PRODUCTS	TONS PER 24 HOURS	POUNDS PER HOUR	GRAMS PER SECOND	NEW SURFACE SQUARE CENTIMETRES PER SECOND
MILL DISCHARGE	4.20	350	44.2	
RETURN SAND	0.60	50	6.3	
CLASS.OVERFLOW	3.60	300	37.9	210500

GROSS POWER DELIVERED TO MILL	3095	FT.POUNDS PER SEC.
NET POWER ABSORBED IN CRUSHING	2420	FT.POUNDS PER SEC.

NOTE:- 6.45 SQ.CM. = 1 SQ.INCH	NEW SURFACE	
EFFICIENCY	SQUARE CENTIMETRES	SQUARE INCHES
GROSS - 1 FOOT-POUND PRODUCED	68.0	
NET - 1 FOOT-POUND PRODUCED	87.0	13.5

Mill Test No. 27 Date Feb. 3 1936 Page

CRUSHING MEDIA.

Lbs. 1¾ Inch
Lbs. 1½ Inch
Lbs. Inch
Lbs. Inch

Total 1126 Lbs. -------- Balls.

Mill Volume------ 10.8 Cu. Ft.

Occupy 35.8 Percent Mill Vol.

MILL.

Pulp 33.7 Percent Water.
66.3 Percent Solids.

Speed -------- 42.9 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 75.7

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

CLASSIFIER.

Slope------- 1.26 Inches per Foot.
Strokes --- 24.7 Per Minute.
Return Sand 51.8 Dry Lbs. per Hr.
\+
Water ------ 28.0 Lbs. per Hour.

Overflow
Solids--- 300 Dry Lbs. per Hr.
Water---- 596 Pounds per Hour.

Liquid-Solid Ratio 1.978 : 1

BELT FEEDER.

Vernier Setting -------- 31.0
Feed-Dry Pounds per Hr.- 300.0
Strokes per minute------ 39.2
Pounds per Stroke------- 1.28

TIME.

Duration of Test 5.2 Hours.
Preparat. Period 4.2 Hours.
Sampling Period 1.0 Hours.

WATER

		At Start.	At End.
No.1 Cock (Feed Water) Dial Setting-------	3.6	Lbs. per Hr. 164.0	Lbs. per Hr.
No.2 Cock (To Classifier) Dial Setting-------	-	Lbs. per Hr. -	Lbs. per Hr.
No.3 Cock (to Mill Disch.) Dial Setting-------	5.525	Lbs. per Hr. 436.0	Lbs. per Hr.
		Total per Hr. 600.	Total per Hr.

POWER.

214 Volts. 20.8 Amps. Wattmeter 4.60 KWH per Hr.

Input to Motor 6.14 H.P. Motor Efficiency 78.9 Percent.

Power Delivered to Mill -------------------- 4.84 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 1.08 H.P.
Power absorbed in Crushing ----------------- 3.76 H.P.

Mill Test No. 27 cont'd. Date Feb. 3 1936 Page

MESH	RET'N SAND % WT.	MILL DISCH. % WT.	MILL FEED % WT.	MILL FEED SURFACE. S. CM÷100	SQ. CM. PER GRAM / 100	CLASSIF. O'FLOW SURFACE S.CM÷100	CLASS. O'FLOW % WT.
-3 +4					0.35		
+6				As in	0.45		
+8				Test 23	0.50		
+10					0.60		
+14					0.70		
+20					0.90		
+28	1.3	0.3			1.05		
+35	2.0	0.3			1.40		
+48	6.2	1.1			1.75		
+65	13.1	2.9			2.35	1.4	0.6
+100	28.3	9.1			3.15	18.2	5.8
+150	17.8	11.0			4.25	44.6	10.5
+200	11.8	14.8			5.50	85.3	15.5
-200	19.5	60.5			75.00	5070.0	67.6
TOTAL	100.0	100.0		100.0	SQ. CM. PER GRAM	5219.5	100.0

CLASSIFIER OVERFLOW (FINISHED PROD.)	5220	SQ.CM. PER GRAM
MILL FEED	100	SQ.CM. PER GRAM
NEW SURFACE	5120	SQ.CM. PER GRAM

DRY PRODUCTS	TONS PER 24 HOURS	POUNDS PER HOUR	GRAMS PER SECOND	NEW SURFACE SQUARE CENTIMETRES PER SECOND
MILL DISCHARGE	4.22	352	44.4	
RETURN SAND	0.62	52	6.6	
CLASS.OVERFLOW	3.60	300	37.8	194000

GROSS POWER DELIVERED TO MILL	2660	FT.POUNDS PER SEC.
NET POWER ABSORBED IN CRUSHING	2070	FT.POUNDS PER SEC.

NOTE:- 6.45 SQ.CM. = 1 SQ.INCH	NEW SURFACE	
EFFICIENCY	SQUARE CENTIMETRES	SQUARE INCHES
GROSS - 1 FOOT-POUND PRODUCED	73.0	
NET - 1 FOOT-POUND PRODUCED	93.8	14.5

Mill Test No. 28 Date Feb. 3 1936 Page

CRUSHING MEDIA.	MILL.
Lbs. 1¾ Inch Lbs. 1½ Inch Lbs. Inch Lbs. Inch	Pulp 38.8 Percent Water. 61.2 Percent Solids.
Total 1121 Lbs. --------- Balls	Speed --------- 42.7 R.P.M. Critical Speed 56.7 R.P.M. Percent of Crit. Speed 75.4
Mill Volume------ 10.8 Cu. Ft. Occupy 35.6 Percent Mill Vol.	Oversize Dry Lbs.per Hr. + Water--- --- Lbs.per Hr.

CLASSIFIER.	BELT FEEDER.
Slope------- 1.26 Inches per Foot. Strokes ----24.6 Per Minute. Return Sand-65.4 Dry Lbs. per Hr. + Water ------35.4 Lbs. per Hour.	Vernier Setting -------- 31.0 Feed-Dry Pounds per Hr.-300.0 Strokes per minute------ 39.2 Pounds per Stroke------- 1.28
Overflow Solids--- 300 Dry Lbs. per Hr. Water---- 593 Pounds per Hour. Liquid-Solid Ratio 1.95 : 1	TIME. Duration of Test 5.0 Hours. Preparat. Period 4.0 Hours. Sampling Period 1.0 Hours.

WATER

		At Start.		At End.
No.1 Cock (Feed Water) Dial Setting-------	4.075	Lbs. per Hr.	204	Lbs. per Hr.
No.2 Cock (To Classifier) Dial Setting-------	-	Lbs. per Hr.	-	Lbs. per Hr.
No.3 Cock (to Mill Disch.) Dial Setting-------	5.32	Lbs. per Hr.	397	Lbs. per Hr.
		Total per Hr.	601	Total per Hr.

POWER.

214 Volts. 20.8 Amps. Wattmeter 4.61 KWH per Hr.

Input to Motor 6.14 H.P. Motor Efficiency 79.0 Percent.

Power Delivered to Mill -------------------- 4.85 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 1.08 H.P.
Power absorbed in Crushing ----------------- 3.77 H.P.

Mill Test No. 28 cont'd. Date Feb. 3 1936 Page

MESH	RET'N SAND % WT.	MILL DISCH. % WT.	MILL FEED % WT.	MILL FEED SURFACE. S. CM÷100	SQ. CM. PER GRAM / 100	CLASSIF. O'FLOW SURFACE S.CM÷100	CLASS. O'FLOW % WT.
-3 +4					0.35		
+6				As in	0.45		
+8				Test 23	0.50		
+10					0.60		
+14					0.70		
+20					0.90		
+28	1.7	0.4			1.05		
+35	2.1	0.4			1.40		
+48	6.2	1.5			1.75		
+65	13.2	3.6			2.35	1.9	0.8
+100	28.4	10.3			3.15	20.8	6.6
+150	17.5	11.7			4.25	47.6	11.2
+200	12.0	14.9			5.50	86.4	15.7
-200	18.9	57.2			69.00	4540.0	65.7
TOTAL	100.0	100.0		100.0	SQ. CM. PER GRAM	4696.7	100.0

CLASSIFIER OVERFLOW (FINISHED PROD.)	4697	SQ.CM. PER GRAM
MILL FEED	100	SQ.CM. PER GRAM
NEW SURFACE	4597	SQ.CM. PER GRAM

DRY PRODUCTS	TONS PER 24 HOURS	POUNDS PER HOUR	GRAMS PER SECOND	NEW SURFACE SQUARE CENTIMETRES PER SECOND
MILL DISCHARGE	4.38	366	46.2	
RETURN SAND	0.79	66	8.3	
CLASS.OVERFLOW	3.59	300	37.9	174100

GROSS POWER DELIVERED TO MILL	2665	FT.POUNDS PER SEC.
NET POWER ABSORBED IN CRUSHING	2065	FT.POUNDS PER SEC.

NOTE:- 6.45 SQ.CM. = 1 SQ.INCH	NEW SURFACE	
EFFICIENCY	SQUARE CENTIMETRES	SQUARE INCHES
GROSS - 1 FOOT-POUND PRODUCED	65.4	
NET - 1 FOOT-POUND PRODUCED	84.3	13.1

Mill Test No. 29 Date Feb. 12 1936 Page

CRUSHING MEDIA.

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

Total 1116 Lbs. --------- Balls.

Mill Volume------ 10.8 Cu. Ft.

Occupy 35.5 Percent Mill Vol.

MILL.

Pulp 29.8 Percent Water.
70.2 Percent Solids.

Speed --------- 42.7 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 75.2

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

CLASSIFIER.

Slope------- 1.26 Inches per Foot.
Strokes ----25.4 Per Minute.
Return Sand- 150 Dry Lbs. per Hr.
+
Water ------ 79 Lbs. per Hour.

Overflow
Solids--- 415 Dry Lbs. per Hr.
Water---- 831 Pounds per Hour.

Liquid-Solid Ratio 2.015: 1

BELT FEEDER.

Vernier Setting --------- 42.0
Feed-Dry Pounds per Hr.-415.0
Strokes per minute------ 39.5
Pounds per Stroke------- 1.75

TIME.

Duration of Test 3.5 Hours.
Preparat. Period 2.8 Hours.
Sampling Period 0.7 Hours.

WATER

		At Start.		At End.
No.1 Cock (Feed Water) Dial Setting--------	3.775	Lbs. per Hr.	178	Lbs. per Hr.
No.2 Cock (To Classifier) Dial Setting-------	-	Lbs. per Hr.	-	Lbs. per Hr.
No.3 Cock (to Mill Disch.) Dial Setting--------	6.825	Lbs. per Hr.	654	Lbs. per Hr.
		Total per Hr.	832	Total per Hr.

POWER.

214 Volts. 20.7 Amps. Wattmeter 4.65 KWH per Hr.

Input to Motor 6.2 H.P. Motor Efficiency 79.0 Percent.

Power Delivered to Mill --------------------- 4.90 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 1.08 H.P.
Power absorbed in Crushing ------------------ 3.82 H.P.

Mill Test No. 29 cont'd. Date Feb. 12 1936 Page

MESH	RET'N SAND % WT.	MILL DISCH. % WT.	MILL FEED % WT.	MILL FEED SURFACE. S. CM÷100	SQ. CM. PER GRAM / 100	CLASSIF. O'FLOW SURFACE S.CM÷100	CLASS. O'FLOW % WT.
-3 +4					0.35		
+6				As in	0.45		
+8				Test 23	0.50		
+10					0.60		
+14					0.70		
+20					0.90		
+28	0.9	0.6			1.05		
+35	1.2	0.4			1.40		
+48	4.4	1.5			1.75		
+65	12.4	4.3			2.35	2.35	1.0
+100	29.6	14.1			3.15	27.1	8.6
+150	20.7	15.4			4.25	60.3	14.2
+200	13.4	16.5			5.50	100.1	18.2
-200	17.4	47.2			69.00	4010.0	58.1
TOTAL	100.0	100.0		100.0	SQ. CM. PER GRAM	4199.8	100.1

CLASSIFIER OVERFLOW (FINISHED PROD.)	4200	SQ.CM. PER GRAM
MILL FEED	100	SQ.CM. PER GRAM
NEW SURFACE	4100	SQ.CM. PER GRAM

DRY PRODUCTS	TONS PER 24 HOURS	POUNDS PER HOUR	GRAMS PER SECOND	NEW SURFACE SQUARE CENTIMETRES PER SECOND
MILL DISCHARGE	6.78	565	71.3	
RETURN SAND	1.80	150	18.9	
CLASS.OVERFLOW	4.98	415	52.4	215000

GROSS POWER DELIVERED TO MILL	2695	FT.POUNDS PER SEC.
NET POWER ABSORBED IN CRUSHING	2100	FT.POUNDS PER SEC.

NOTE:- 6.45 SQ.CM. = 1 SQ.INCH	NEW SURFACE	
EFFICIENCY	SQUARE CENTIMETRES	SQUARE INCHES
GROSS - 1 FOOT-POUND PRODUCED	79.7	
NET - 1 FOOT-POUND PRODUCED	102.2	15.9

Mill Test No. **30** Date **Feb. 12** 1936 Page

CRUSHING MEDIA.

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

Total **1110** Lbs. -------- **Balls.**

Mill Volume------ **10.8** Cu. Ft.

Occupy **35.3** Percent Mill Vol.

MILL.

Pulp **29.8** Percent Water.
70.2 Percent Solids.

Speed -------- **42.8** R.P.M.
Critical Speed **56.7** R.P.M.
Percent of Crit. Speed **75.6**

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

CLASSIFIER.

Slope------- **1.26** Inches per Foot.
Strokes ----**25.4** Per Minute.
Return Sand- **234** Dry Lbs. per Hr.
+
Water ------ **104** Lbs. per Hour.

Overflow
Solids--- **505** Dry Lbs. per Hr.
Water---- **998** Pounds per Hour.

Liquid-Solid Ratio **1.957** : 1

BELT FEEDER.

Vernier Setting -------- **50.0**
Feed-Dry Pounds per Hr.-**505.0**
Strokes per minute------ **36.9**
Pounds per Stroke------- **2.03**

TIME.

Duration of Test **4.7** Hours.
Preparat. Period **3.3** Hours.
Sampling Period **1.4** Hours.

WATER

		At Start.	At End.
No.1 Cock (Feed Water) Dial Setting-------	**4.2**	Lbs. per Hr. **214**	Lbs. per Hr.
No.2 Cock (To Classifier) Dial Setting-------	-	Lbs. per Hr. -	Lbs. per Hr.
No.3 Cock (to Mill Disch.) Dial Setting-------	**7.65**	Lbs. per Hr. **778**	Lbs. per Hr.
		Total per Hr. **992**	Total per Hr.

POWER.

214 Volts. **21.3** Amps. Wattmeter **4.72** KWH per Hr.

Input to Motor **6.28** H.P. Motor Efficiency **79.3** Percent.

Power Delivered to Mill -------------------- **4.98** H.P.
Power lost in Mill Bearings, Drive Gear, Etc. **1.08** H.P.
Power absorbed in Crushing ----------------- **3.90** H.P.

Mill Test No. 30 cont'd. Date Feb. 12 1936 Page

MESH	RET'N SAND % WT.	MILL DISCH. % WT.	MILL FEED % WT.	MILL FEED SURFACE. S. CM÷100	SQ. CM. PER GRAM / 100	CLASSIF. O'FLOW SURFACE S.CM÷100	CLASS. O'FLOW % WT.
-3 +4					0.35		
+6				As in	0.45		
+8				Test 23	0.50		
+10					0.60		
+14					0.70		
+20					0.90		
+28	1.3	0.8			1.05		
+35	1.2	0.5			1.40		
+48	5.4	2.2			1.75		
+65	14.3	5.8			2.35	4.0	1.7
+100	31.9	17.8			3.15	36.9	11.7
+150	19.7	17.2			4.25	71.4	16.8
+200	11.7	15.9			5.50	101.1	18.4
-200	14.5	39.8			64.50	3320.0	51.5
TOTAL	100.0	100.0		100.0	SQ. CM. PER GRAM	3533.4	100.1

CLASSIFIER OVERFLOW (FINISHED PROD.)	3533	SQ.CM. PER GRAM
MILL FEED	100	SQ.CM. PER GRAM
NEW SURFACE	3433	SQ.CM. PER GRAM

DRY PRODUCTS	TONS PER 24 HOURS	POUNDS PER HOUR	GRAMS PER SECOND	NEW SURFACE SQUARE CENTIMETRES PER SECOND
MILL DISCHARGE	8.86	739	93.4	
RETURN SAND	2.81	234	26.6	
CLASS.OVERFLOW	6.05	505	66.8	229500

GROSS POWER DELIVERED TO MILL	2740	FT.POUNDS PER SEC.
NET POWER ABSORBED IN CRUSHING	2145	FT.POUNDS PER SEC.

NOTE:- 6.45 SQ.CM. = 1 SQ.INCH	NEW SURFACE	
EFFICIENCY	SQUARE CENTIMETRES	SQUARE INCHES
GROSS - 1 FOOT-POUND PRODUCED	83.8	
NET - 1 FOOT-POUND PRODUCED	107.0	16.6

Mill Test No. 31 Date **Mar. 4 1936** Page

CRUSHING MEDIA.

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

Total **1163** Lbs. -------- **Balls.**

Mill Volume------ **10.0** Cu. Ft.

Occupy **40.0** Percent Mill Vol.

MILL.

Pulp **28.8** Percent Water.
71.2 Percent Solids.

Speed -------- **42.7** R.P.M.
Critical Speed **56.7** R.P.M.
Percent of Crit. Speed **75.2**

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

CLASSIFIER.

Slope------- **1.26** Inches per Foot.
Strokes ----**25.3** Per Minute.
Return Sand- **99** Dry Lbs. per Hr.
+
Water ------ **38** Lbs. per Hour.

Overflow
Solids--- **413** Dry Lbs. per Hr.
Water---- **824** Pounds per Hour.

Liquid-Solid Ratio **2.02** : 1

BELT FEEDER.

Vernier Setting -------- **42.0**
Feed-Dry Pounds per Hr.-**413.0**
Strokes per minute------ **39.8**
Pounds per Stroke------- **1.73**

TIME.

Duration of Test **5.0** Hours.
Preparat. Period **4.25** Hours.
Sampling Period **0.75** Hours.

WATER

		At Start.	At End.
No.1 Cock (Feed Water) Dial Setting	**3.775**	Lbs. per Hr.	**178.0** Lbs. per Hr.
No.2 Cock (To Classifier) Dial Setting	-	Lbs. per Hr.	- Lbs. per Hr.
No.3 Cock (to Mill Disch.) Dial Setting	**6.825**	Lbs. per Hr.	**654.0** Lbs. per Hr.
		Total per Hr.	**832** Total per Hr.

POWER.

214 Volts. **22.4** Amps. Wattmeter **5.00** KWH per Hr.

Input to Motor **6.67** H.P. Motor Efficiency **79.5** Percent.

Power Delivered to Mill -------------------- **5.31** H.P.
Power lost in Mill Bearings, Drive Gear, Etc. **1.08** H.P.
Power absorbed in Crushing ----------------- **4.23** H.P.

Mill Test No. 31 cont'd. Date Mar. 4 1936 Page

MESH	RET'N SAND % WT.	MILL DISCH. % WT.	MILL FEED % WT.	MILL FEED SURFACE. S. CM÷100	SQ. CM. PER GRAM / 100	CLASSIF. O'FLOW SURFACE S.CM÷100	CLASS. O'FLOW % WT.
-3 +4					0.35		
+6				As in	0.45		
+8				Test 23	0.50		
+10	1.7	0.5			0.60		
+14	0.2	-			0.70		
+20	0.1	-			0.90		
+28	0.5	0.2			1.05		
+35	1.1	0.3			1.40		
+48	4.7	1.1			1.75		
+65	12.6	3.5			2.35	2.35	1.0
+100	30.2	12.5			3.15	27.1	8.6
+150	19.1	14.4			4.25	57.4	13.5
+200	12.7	15.9			5.50	93.0	16.9
-200	11.1	51.7			82.00	4910.0	59.9
TOTAL	100.0	100.1		100.0	SQ. CM. PER GRAM	5089.8	99.9

CLASSIFIER OVERFLOW (FINISHED PROD.)	5090	SQ.CM. PER GRAM
MILL FEED	100	SQ.CM. PER GRAM
NEW SURFACE	4990	SQ.CM. PER GRAM

DRY PRODUCTS	TONS PER 24 HOURS	POUNDS PER HOUR	GRAMS PER SECOND	NEW SURFACE SQUARE CENTIMETRES PER SECOND
MILL DISCHARGE	6.15	512	64.7	
RETURN SAND	1.20	99	12.5	
CLASS. OVERFLOW	4.95	413	52.2	261000

GROSS POWER DELIVERED TO MILL	2920	FT. POUNDS PER SEC.
NET POWER ABSORBED IN CRUSHING	2330	FT. POUNDS PER SEC.

NOTE:- 6.45 SQ.CM. = 1 SQ.INCH	NEW SURFACE	
EFFICIENCY	SQUARE CENTIMETRES	SQUARE INCHES
GROSS - 1 FOOT-POUND PRODUCED	89.4	
NET - 1 FOOT-POUND PRODUCED	112.0	17.4

Mill Test No. 32 Date Mar. 4 1936 Page

CRUSHING MEDIA.

Lbs. 1¾ Inch
Lbs. 1½ Inch
Lbs. Inch
Lbs. Inch

Total 1159 Lbs. -------- Balls.

Mill Volume------ 10.0 Cu. Ft.

Occupy 39.8 Percent Mill Vol.

MILL.

Pulp 29.2 Percent Water.
70.8 Percent Solids.

Speed -------- 42.6 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 75.1

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

CLASSIFIER.

Slope------- 1.26 Inches per Foot.
Strokes ----24.6 Per Minute.
Return Sand- 179 Dry Lbs. per Hr.
+
Water ------ 71 Lbs. per Hour.

Overflow
Solids--- 503 Dry Lbs. per Hr.
Water---- 989 Pounds per Hour.

Liquid-Solid Ratio 1.94 : 1

BELT FEEDER.

Vernier Setting -------- 50.0
Feed-Dry Pounds per Hr.-503.0
Strokes per minute------ 39.9
Pounds per Stroke------- 2.10

TIME.

Duration of Test 4.0 Hours.
Preparat. Period 3.1 Hours.
Sampling Period 0.9 Hours.

WATER

		At Start.	At End.
No.1 Cock (Feed Water) Dial Setting-------	4.2	Lbs. per Hr.	214 Lbs. per Hr.
No.2 Cock (To Classifier) Dial Setting-------	-	Lbs. per Hr.	- Lbs. per Hr.
No.3 Cock (to Mill Disch.) Dial Setting-------	7.65	Lbs. per Hr.	778 Lbs. per Hr.
		Total per Hr.	992 Total per Hr.

POWER.

214 Volts. 22.5 Amps. Wattmeter 5.05 KWH per Hr.

Input to Motor 6.73 H.P. Motor Efficiency 79.6 Percent.

Power Delivered to Mill -------------------- 5.37 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 1.08 H.P.
Power absorbed in Crushing ----------------- 4.29 H.P.

Mill Test No. 32 cont'd. Date Mar. 4 1936 Page

MESH	RET'N SAND % WT.	MILL DISCH. % WT.	MILL FEED % WT.	MILL FEED SURFACE. S. CM÷100	SQ. CM. PER GRAM / 100	CLASSIF. O'FLOW SURFACE S.CM÷100	CLASS. O'FLOW % WT.
-3 +4					0.35		
+6				As in	0.45		
+8				Test 23	0.50		
+10	4.9	1.4			0.60		
+14	0.3	0.1			0.70		
+20	0.2	0.1			0.90		
+28	0.7	0.3			1.05		
+35	1.3	0.5			1.40		
+48	5.0	1.6			1.75	0.2	0.1
+65	13.5	5.0			2.35	3.8	1.6
+100	30.1	15.8			3.15	35.3	11.2
+150	18.3	15.9			4.25	65.9	15.5
+200	11.1	15.4			5.50	94.6	17.2
-200	14.6	43.9			74.00	4025.0	54.4
TOTAL	100.0	100.0		100.0	SQ. CM. PER GRAM	4224.8	100.0

CLASSIFIER OVERFLOW (FINISHED PROD.)	4225	SQ.CM. PER GRAM
MILL FEED	100	SQ.CM. PER GRAM
NEW SURFACE	4125	SQ.CM. PER GRAM

DRY PRODUCTS	TONS PER 24 HOURS	POUNDS PER HOUR	GRAMS PER SECOND	NEW SURFACE SQUARE CENTIMETRES PER SECOND
MILL DISCHARGE	8.20	682	86.1	
RETURN SAND	2.15	179	22.6	
CLASS.OVERFLOW	6.05	503	63.5	262000

GROSS POWER DELIVERED TO MILL	2955	FT.POUNDS PER SEC.
NET POWER ABSORBED IN CRUSHING	2360	FT.POUNDS PER SEC.

NOTE:- 6.45 SQ.CM. = 1 SQ.INCH	NEW SURFACE	
EFFICIENCY	SQUARE CENTIMETRES	SQUARE INCHES
GROSS - 1 FOOT-POUND PRODUCED	88.8	
NET - 1 FOOT-POUND PRODUCED	111.0	17.2

Mill Test No. 33 Date Mar. 25 1936 Page

CRUSHING MEDIA.

Lbs. 1¾ Inch
Lbs. 1½ Inch
Lbs. Inch
Lbs. Inch

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

Mill Volume------ 10.0 Cu. Ft.

Occupy 40.0 Percent Mill Vol.

MILL.

Pulp 28.8 Percent Water.
71.2 Percent Solids.

Speed -------- 42.4 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 74.8

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

CLASSIFIER.

Slope------- 1.26 Inches per Foot.
Strokes ---- 24.5 Per Minute.
Return Sand- 313 Dry Lbs. per Hr.
+
Water ------ 117 Lbs. per Hour.

Overflow
Solids--- 592 Dry Lbs. per Hr.
Water----1184 Pounds per Hour.

Liquid-Solid Ratio 1.997: 1

BELT FEEDER.

Vernier Setting -------- 61.0
Feed-Dry Pounds per Hr.-592.0
Strokes per minute------ 39.5
Pounds per Stroke------- 2.50

TIME.

Duration of Test 5.3 Hours.
Preparat. Period 4.3 Hours.
Sampling Period 1.0 Hours.

WATER

		At Start.	At End.
No.1 Cock (Feed Water) Dial Setting-------	4.7	Lbs. per Hr. 253.1	Lbs. per Hr.
No.2 Cock (To Classifier) Dial Setting-------	3.0	Lbs. per Hr. 177.4	Lbs. per Hr.
No.3 Cock (to Mill Disch.) Dial Setting-------	7.55	Lbs. per Hr. 759.5	Lbs. per Hr.
		Total per Hr. 1190	Total per Hr.

POWER.

214 Volts. 23.5 Amps. Wattmeter 5.23 KWH per Hr.

Input to Motor 6.98 H.P. Motor Efficiency 80.0 Percent.

Power Delivered to Mill -------------------- 5.58 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 1.07 H.P.
Power absorbed in Crushing ----------------- 4.51 H.P.

Mill Test No. 33 cont'd. Date Mar. 25 19 Page 36

MESH	RET'N SAND % WT.	MILL DISCH. % WT.	MILL FEED % WT.	MILL FEED SURFACE. S. CM÷100	SQ. CM. PER GRAM / 100	CLASSIF. O'FLOW SURFACE S.CM÷100	CLASS. O'FLOW % WT.
-3 +4	0.3				0.35		
+6	2.7	0.7		As in	0.45		
+8	1.6	0.7		Test 23	0.50		
+10	0.9	0.5			0.60		
+14	0.5	0.3			0.70		
+20	0.2	0.2			0.90		
+28	1.0	0.7			1.05		
+35	1.6	0.8			1.40		
+48	6.2	2.5			1.75	0.4	0.2
+65	15.5	6.8			2.35	4.9	2.2
+100	31.2	19.2			3.15	44.0	13.9
+150	16.7	16.8			4.25	71.8	16.9
+200	10.0	14.2			5.50	93.6	17.0
-200	11.5	36.6			72.00	3595.0	49.8
TOTAL	99.9	100.0		100.0	SQ. CM. PER GRAM	3809.7	100.0

CLASSIFIER OVERFLOW (FINISHED PROD.)	3810	SQ.CM. PER GRAM
MILL FEED	100	SQ.CM. PER GRAM
NEW SURFACE	3710	SQ.CM. PER GRAM

DRY PRODUCTS	TONS PER 24 HOURS	POUNDS PER HOUR	GRAMS PER SECOND	NEW SURFACE SQUARE CENTIMETRES PER SECOND
MILL DISCHARGE	10.86	905	114.4	
RETURN SAND	3.76	313	39.5	
CLASS.OVERFLOW	7.10	592	74.9	278000

GROSS POWER DELIVERED TO MILL	3070	FT.POUNDS PER SEC.
NET POWER ABSORBED IN CRUSHING	2480	FT.POUNDS PER SEC.

NOTE:- 6.45 SQ.CM. = 1 SQ.INCH	NEW SURFACE	
EFFICIENCY	SQUARE CENTIMETRES	SQUARE INCHES
GROSS - 1 FOOT-POUND PRODUCED	90.6	
NET - 1 FOOT-POUND PRODUCED	112.0	17.4

Mill Test No. 34   Date Apr. 1 1936 Page

CRUSHING MEDIA.

Lbs. 1¾ Inch
Lbs. 1½ Inch
Lbs. Inch
Lbs. Inch

Total 1168 Lbs. -------- Balls

Mill Volume------ 10.0 Cu. Ft.

Occupy 40.1 Percent Mill Vol.

MILL.

Pulp 30.2 Percent Water.
69.8 Percent Solids.

Speed -------- 39.3 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 69.3

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

CLASSIFIER.

Slope------- 1.26 Inches per Foot.
Strokes ----25.2 Per Minute.
Return Sand- 50 Dry Lbs. per Hr.
+
Water ------ 18 Lbs. per Hour.

Overflow
Solids--- 300 Dry Lbs. per Hr.
Water---- 604 Pounds per Hour.

Liquid-Solid Ratio 2.01 : 1

BELT FEEDER.

Vernier Setting -------- 31.0
Feed-Dry Pounds per Hr.-300.0
Strokes per minute------ 39.1
Pounds per Stroke------- 1.28

TIME.

Duration of Test 5.0 Hours.
Preparat. Period 4.2 Hours.
Sampling Period 0.8 Hours.

WATER

		At Start.		At End.
No.1 Cock (Feed Water) Dial Setting-------	3.3	Lbs. per Hr.	134	Lbs. per Hr.
No.2 Cock (To Classifier) Dial Setting-------	-	Lbs. per Hr.	-	Lbs. per Hr.
No.3 Cock (to Mill Disch.) Dial Setting-------	5.7	Lbs. per Hr.	470	Lbs. per Hr.
		Total per Hr.	604	Total per Hr.

POWER.

214 Volts. 20.7 Amps.   Wattmeter 4.57 KWH per Hr.

Input to Motor 6.08 H.P.   Motor Efficiency 79.6 Percent.

Power Delivered to Mill -------------------- 4.84 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 0.99 H.P.
Power absorbed in Crushing ----------------- 3.85 H.P.

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MESH	RET'N SAND % WT.	MILL DISCH. % WT.	MILL FEED % WT.	MILL FEED SURFACE. S. CM÷100	SQ. CM. PER GRAM / 100	CLASSIF. O'FLOW SURFACE S.CM÷100	CLASS. O'FLOW % WT.
-3 +4		0.2			0.35		
+6	0.5	0.2		As in	0.45		
+8	0.7	0.1		Test 23	0.50		
+10	0.6	0.1			0.60		
+14	0.4	0.1			0.70		
+20	0.3	-			0.90		
+28	0.7	0.1			1.05		
+35	1.0	0.2			1.40		
+48	3.9	0.7			1.75		
+65	11.4	2.2			2.35	0.9	0.4
+100	28.7	18.0			3.15	15.7	5.0
+150	18.5	11.2			4.25	44.6	10.5
+200	13.6	15.4			5.50	87.0	15.8
-200	19.6	61.4			83.50	5700.0	68.3
TOTAL	99.9	99.9		100.0	SQ. CM. PER GRAM	5848.2	100.0

CLASSIFIER OVERFLOW (FINISHED PROD.)	5848	SQ.CM. PER GRAM
MILL FEED	100	SQ.CM. PER GRAM
NEW SURFACE	5748	SQ.CM. PER GRAM

DRY PRODUCTS	TONS PER 24 HOURS	POUNDS PER HOUR	GRAMS PER SECOND	NEW SURFACE SQUARE CENTIMETRES PER SECOND
MILL DISCHARGE	4.20	350	44.2	
RETURN SAND	0.60	50	6.3	
CLASS.OVERFLOW	3.60	300	37.9	217500

GROSS POWER DELIVERED TO MILL	2660	FT.POUNDS PER SEC.
NET POWER ABSORBED IN CRUSHING	2120	FT.POUNDS PER SEC.

NOTE:- 6.45 SQ.CM. = 1 SQ.INCH	NEW SURFACE	
EFFICIENCY	SQUARE CENTIMETRES	SQUARE INCHES
GROSS - 1 FOOT-POUND PRODUCED	81.8	
NET - 1 FOOT-POUND PRODUCED	103.0	16.0

Mill Test No. 35 Date Apr. 15 1936 Page

CRUSHING MEDIA.	MILL.
Lbs. 1¾ Inch Lbs. 1½ Inch Lbs. Inch Lbs. Inch	Pulp 30.5 Percent Water. 69.5 Percent Solids.
Total 1169 Lbs. -------- Balls.	Speed -------- 42.7 R.P.M. Critical Speed 56.7 R.P.M. Percent of Crit. Speed 75.2
Mill Volume------ 10.0 Cu. Ft. Occupy 40.2 Percent Mill Vol.	Oversize Dry Lbs.per Hr. + Water--- --- Lbs.per Hr.

CLASSIFIER.	BELT FEEDER.
Slope------- 1.26 Inches per Foot. Strokes ----24.8 Per Minute. Return Sand- 41 Dry Lbs. per Hr. + Water ------ 15 Lbs. per Hour.	Vernier Setting -------- 31.0 Feed-Dry Pounds per Hr.-298.0 Strokes per minute------ 39.5 Pounds per Stroke------- 1.25
Overflow Solids--- 304 Dry Lbs. per Hr. Water---- 606 Pounds per Hour. Liquid-Solid Ratio 2.013: 1	**TIME.** Duration of Test 5.0 Hours. Preparat. Period 4.2 Hours. Sampling Period 0.8 Hours.

WATER

	At Start.	At End.
No.1 Cock (Feed Water) Dial Setting-------	3.3 Lbs. per Hr.	134 Lbs. per Hr.
No.2 Cock (To Classifier) Dial Setting-------	- Lbs. per Hr.	- Lbs. per Hr.
No.3 Cock (to Mill Disch.) Dial Setting-------	5.7 Lbs. per Hr.	470 Lbs. per Hr.
	Total per Hr.	604 Total per Hr.

POWER.

214 Volts. 21.3 Amps. Wattmeter 4.77 KWH per Hr.

Input to Motor 6.36 H.P. Motor Efficiency 79.2 Percent.

Power Delivered to Mill -------------------- 5.04 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 1.08 H.P.
Power absorbed in Crushing ----------------- 3.96 H.P.

Mill Test No. 35 cont'd. Date Apr. 15 19 36 Page

MESH	RET'N SAND % WT.	MILL DISCH. % WT.	MILL FEED % WT.	MILL FEED SURFACE. S. CM÷100	SQ. CM. PER GRAM / 100	CLASSIF. O'FLOW SURFACE S.CM÷100	CLASS. O'FLOW % WT.
-3 +4	0.1				0.35		
+6	0.5			As in	0.45		
+8	0.5	0.1		Test 23	0.50		
+10	0.2	0.1			0.60		
+14	0.1	-			0.70		
+20	0.1	-			0.90		
+28	0.4	0.1			1.05		
+35	1.0	0.2			1.40		
+48	4.5	0.6			1.75		
+65	13.0	1.9			2.35	0.9	0.4
+100	30.2	7.6			3.15	15.1	4.8
+150	18.0	10.7			4.25	41.6	9.8
+200	12.7	15.0			5.50	83.6	15.2
-200	18.7	63.7			85.00	5940.0	69.8
TOTAL	100.0	100.0		100.0	SQ. CM. PER GRAM	6081.2	100.0

CLASSIFIER OVERFLOW (FINISHED PROD.)	6081	SQ.CM. PER GRAM
MILL FEED	100	SQ.CM. PER GRAM
NEW SURFACE	5981	SQ.CM. PER GRAM

DRY PRODUCTS	TONS PER 24 HOURS	POUNDS PER HOUR	GRAMS PER SECOND	NEW SURFACE SQUARE CENTIMETRES PER SECOND
MILL DISCHARGE	4.14	345	43.6	
RETURN SAND	0.49	41	5.2	
CLASS. OVERFLOW	3.65	304	38.4	230000

GROSS POWER DELIVERED TO MILL	2770	FT.POUNDS PER SEC.
NET POWER ABSORBED IN CRUSHING	2180	FT.POUNDS PER SEC.

NOTE:- 6.45 SQ.CM. = 1 SQ.INCH	NEW SURFACE	
EFFICIENCY	SQUARE CENTIMETRES	SQUARE INCHES
GROSS - 1 FOOT-POUND PRODUCED	83.1	
NET - 1 FOOT-POUND PRODUCED	105.5	16.4

Mill Test No. 36 Date Apr. 15 1936 Page

CRUSHING MEDIA.

Lbs. 1¾ Inch
Lbs. 1½ Inch
Lbs. Inch
Lbs. Inch

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

Mill Volume------ 10.0 Cu. Ft.

Occupy 40.0 Percent Mill Vol.

MILL.

Pulp 30.7 Percent Water.
69.3 Percent Solids.

Speed -------- 47.2 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 83.2

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

CLASSIFIER.

Slope------- 1.26 Inches per Foot.
Strokes ----24.6 Per Minute.
Return Sand- 26 Dry Lbs. per Hr.
+
Water ------ 15 Lbs. per Hour.

Overflow
Solids--- 304 Dry Lbs. per Hr.
Water---- 601 Pounds per Hour.

Liquid-Solid Ratio 1.975 : 1

BELT FEEDER.

Vernier Setting -------- 31.0
Feed-Dry Pounds per Hr.-297.0
Strokes per minute------ 39.5
Pounds per Stroke------- 1.25

TIME.

Duration of Test 3.40 Hours.
Preparat. Period 2.65 Hours.
Sampling Period 0.75 Hours.

WATER

	Dial Setting	At Start.	At End.
No.1 Cock (Feed Water) Dial Setting-------	3.3	Lbs. per Hr. 134	Lbs. per Hr.
No.2 Cock (To Classifier) Dial Setting-------	-	Lbs. per Hr. -	Lbs. per Hr.
No.3 Cock (to Mill Disch.) Dial Setting-------	5.7	Lbs. per Hr. 470	Lbs. per Hr.
		Total per Hr. 604	Total per Hr.

POWER.

214 Volts. 23.5 Amps. Wattmeter 5.22 KWH per Hr.

Input to Motor 6.96 H.P. Motor Efficiency 79.6 Percent.

Power Delivered to Mill -------------------- 5.54 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 1.17 H.P.
Power absorbed in Crushing ----------------- 4.37 H.P.

Mill Test No. 36 cont'd. Date Apr. 15 1936 Page

MESH	RET'N SAND % WT.	MILL DISCH. % WT.	MILL FEED % WT.	MILL FEED SURFACE. S. CM÷100	SQ. CM. PER GRAM / 100	CLASSIF. O'FLOW SURFACE S.CM÷100	CLASS. O'FLOW % WT.
-3 +4					0.35		
+6	1.4			As in	0.45		
+8	0.9	0.1		Test 23.	0.50		
+10	0.4	0.1			0.60		
+14	0.2	-			0.70		
+20	0.1	-			0.90		
+28	0.6	0.1			1.05		
+35	1.2	0.1			1.40		
+48	4.6	0.6			1.75		
+65	12.3	1.8			2.35	1.2	0.5
+100	29.3	6.9			3.15	15.1	4.8
+150	17.7	10.1			4.25	42.5	10.0
+200	12.0	14.7			5.50	84.2	15.3
-200	19.3	65.4			95.00	6590.0	69.4
TOTAL	100.0	99.9		100.0	SQ. CM. PER GRAM	6733.0	100.0

CLASSIFIER OVERFLOW (FINISHED PROD.)	6733	SQ.CM. PER GRAM
MILL FEED	100	SQ.CM. PER GRAM
NEW SURFACE	6633	SQ.CM. PER GRAM

DRY PRODUCTS	TONS PER 24 HOURS	POUNDS PER HOUR	GRAMS PER SECOND	NEW SURFACE SQUARE CENTIMETRES PER SECOND
MILL DISCHARGE	3.96	330	41.7	
RETURN SAND	0.29	26	3.3	
CLASS. OVERFLOW	3.67	304	38.4	254500

GROSS POWER DELIVERED TO MILL	3050	FT. POUNDS PER SEC.
NET POWER ABSORBED IN CRUSHING	2400	FT. POUNDS PER SEC.

NOTE:- 6.45 SQ.CM. = 1 SQ.INCH	NEW SURFACE	
EFFICIENCY	SQUARE CENTIMETRES	SQUARE INCHES
GROSS - 1 FOOT-POUND PRODUCED	83.5	
NET - 1 FOOT-POUND PRODUCED	106.0	16.5

Mill Test No. 37 Date Apr. 24 1936 Page

CRUSHING MEDIA.

Lbs. 1¾ Inch
Lbs. 1½ Inch
Lbs. Inch
Lbs. Inch

Total 1163 Lbs. -------- Balls.

Mill Volume------ 10.8 Cu. Ft.

Occupy 37.0 Percent Mill Vol.

MILL.

Pulp 30.7 Percent Water.
69.3 Percent Solids.

Speed -------- 42.5 R.P.M.
Critical Speed 56.7 R.P.M.
Percent of Crit. Speed 75.0

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

CLASSIFIER.

Slope------- 1.26 Inches per Foot.
Strokes ----24.8 Per Minute.
Return Sand- 256 Dry Lbs. per Hr.
+
Water ------ 88 Lbs. per Hour.

Overflow
Solids--- 609 Dry Lbs. per Hr.
Water---- 1204 Pounds per Hour.

Liquid-Solid Ratio 1.97 : 1

BELT FEEDER.

Vernier Setting -------- 61.0
Feed-Dry Pounds per Hr.- 599.0
Strokes per minute------ 39.3
Pounds per Stroke------- 2.54

TIME.

Duration of Test 4.0 Hours.
Preparat. Period 3.5 Hours.
Sampling Period 0.5 Hours.

WATER

		At Start.	At End.
No.1 Cock (Feed Water) Dial Setting-------	4.7	Lbs. per Hr. 253.1	Lbs. per Hr.
No.2 Cock (To Classifier) Dial Setting-------	3.0	Lbs. per Hr. 177.4	Lbs. per Hr.
No.3 Cock (to Mill Disch.) Dial Setting-------	7.55	Lbs. per Hr. 759.5	Lbs. per Hr.
		Total per Hr. 1190	Total per Hr.

POWER.

214 Volts. 22.5 Amps. Wattmeter 5.015 KWH per Hr.

Input to Motor 6.68 H.P. Motor Efficiency 79.9 Percent.

Power Delivered to Mill -------------------- 5.33 H.P.
Power lost in Mill Bearings, Drive Gear, Etc. 1.08 H.P.
Power absorbed in Crushing ----------------- 4.25 H.P.

Mill Test No. 37 cont'd. Date Apr. 24 1936 Page

MESH	RET'N SAND % WT.	MILL DISCH. % WT.	MILL FEED % WT.	MILL FEED SURFACE. S. CM÷100	SQ. CM. PER GRAM / 100	CLASSIF. O'FLOW SURFACE S.CM÷100	CLASS. O'FLOW % WT.
-3 +4					0.35		
+6	0.1			As in	0.45		
+8	-	0.1		Test 23	0.50		
+10	-	0.1			0.60		
+14	0.1	0.1			0.70		
+20	0.1	0.1			0.90		
+28	0.6	0.4			1.05		
+35	1.5	0.6			1.40		
+48	6.6	2.4			1.75	0.5	0.3
+65	15.7	6.4			2.35	6.4	2.7
+100	31.6	19.4			3.15	45.4	14.4
+150	19.1	17.2			4.25	72.2	17.0
+200	11.4	15.3			5.50	95.2	17.3
-200	13.2	37.9			60.00	2900.0	48.3
TOTAL	100.0	100.0		100.0	SQ. CM. PER GRAM	3119.7	100.0

CLASSIFIER OVERFLOW (FINISHED PROD.)	3120	SQ.CM. PER GRAM
MILL FEED	100	SQ.CM. PER GRAM
NEW SURFACE	3020	SQ.CM. PER GRAM

DRY PRODUCTS	TONS PER 24 HOURS	POUNDS PER HOUR	GRAMS PER SECOND	NEW SURFACE SQUARE CENTIMETRES PER SECOND
MILL DISCHARGE	8.14	865	109.4	
RETURN SAND	3.07	256	32.4	
CLASS.OVERFLOW	5.07	609	77.0	232500

GROSS POWER DELIVERED TO MILL	2930	FT.POUNDS PER SEC.
NET POWER ABSORBED IN CRUSHING	2340	FT.POUNDS PER SEC.

NOTE:- 6.45 SQ.CM. = 1 SQ.INCH	NEW SURFACE	
EFFICIENCY	SQUARE CENTIMETRES	SQUARE INCHES
GROSS - 1 FOOT-POUND PRODUCED	79.4	
NET - 1 FOOT-POUND PRODUCED	99.5	15.4

TABLE 3.

OPEN END MILL - MOISTURE TESTS.

Test No.	Mill Speed R.P.M.	Feed Lbs. Per Hr.	% Moisture Mill Disch'ge.	% -200 Class'r. Overfl.	Return Sand, Lbs. Per Hr.	Horse-power Gross	Horse-power Net	Efficiency Sq. Cm. Per Ft. -Lb. Gross	Efficiency Sq. Cm. Per Ft. -Lb. Net	Lbs. Fe Per Ton C.O.	New Surface Sq. Cm. Per Gm. C.O.
23	42.7	293	30.7	68.2	45	4.81	3.73	76.6	95.0	6.43	5158
27	42.9	300	33.7	67.6	52	4.84	3.76	73.0	93.8	6.90	5120
28	42.7	300	38.8	65.7	66	4.85	3.77	65.4	84.3	6.90	4597

TABLE 4.

OPEN END MILL - FEED TESTS.

Test No.	Mill Speed R.P.M.	Feed Lbs. Per Hr.	% Moisture Mill Disch'ge.	% -200 Class'r. Overfl.	Return Sand, Lbs. Per Hr.	Horse-power Gross	Horse-power Net	Efficiency Sq. Cm. Per Ft. -Lb. Gross	Efficiency Sq. Cm. Per Ft. -Lb. Net	Lbs. Fe Per Ton C.O.	New Surface Sq. Cm. Per Gm. C.O.
23	42.7	293	30.7	68.2	45	4.81	3.73	76.6	95.0	6.43	5158
29	42.7	415	29.8	58.1	150	4.90	3.82	79.7	102.2	4.80	4100
30	42.8	505	29.8	51.5	234	4.98	3.90	83.8	107.0	3.33	3433
37	42.5	599	30.7	48.3	256	5.33	4.25	79.4	99.5	-	3020

QUICK-DISCHARGE MILL - FEED TESTS.

Test No.	Mill Speed R.P.M.	Feed Lbs. Per Hr.	% Moisture Mill Disch'ge.	% -200 Class'r. Overfl.	Return Sand, Lbs. Per Hr.	Horse-power Gross	Horse-power Net	Efficiency Sq. Cm. Per Ft. -Lb. Gross	Efficiency Sq. Cm. Per Ft. -Lb. Net	Lbs. Fe Per Ton C.O.	New Surface Sq. Cm. Per Gm. C.O.
35	42.7	298	30.5	69.8	41	5.04	3.96	83.1	105.5	6.11*	5981
31	42.7	413	28.8	59.9	99	5.31	4.23	89.4	112.0	5.69	4990
32	42.6	503	29.2	54.4	179	5.37	4.29	88.8	111.0	5.36	4125
33	42.4	592	28.8	49.8	313	5.58	4.51	90.6	112.0	5.04	3710

* By extrapolation.

TABLE 5.

OPEN END MILL - SPEED TESTS.

Test No.	Mill Speed R.P.M.	Feed Lbs. Per Hr.	% Moisture Mill Disch'ge.	% -200 Class'r. Overfl.	Return Sand, Lbs. Per Hr.	Horse-power Gross	Horse-power Net	Efficiency Sq. Cm. Per Ft. -Lb. Gross	Efficiency Sq. Cm. Per Ft. -Lb. Net	Efficiency Lbs. Fe Per Ton C.O.	Efficiency New Surface Sq. Cm. Per Gm. C.O.
25	39.8	300	30.3	68.6	67	4.30	3.30	75.9	98.7	6.12	4749
23	42.7	293	30.7	68.2	45	4.81	3.73	76.6	95.0	6.43	5158
24	46.9	295	30.6	69.4	34	5.28	4.11	79.3	89.1	6.84	5412
26	50.6	300	30.3	72.5	50	5.63	4.40	68.0	87.0	7.07	5567

QUICK-DISCHARGE MILL - SPEED TESTS.

Test No.	Mill Speed R.P.M.	Feed Lbs. Per Hr.	% Moisture Mill Disch'ge.	% -200 Class'r. Overfl.	Return Sand, Lbs. Per Hr.	Horse-power Gross	Horse-power Net	Efficiency Sq. Cm. Per Ft. -Lb. Gross	Efficiency Sq. Cm. Per Ft. -Lb. Net	Efficiency Lbs. Fe Per Ton C.O.	Efficiency New Surface Sq. Cm. Per Gm. C.O.
34	39.3	300	30.2	68.3	50	4.84	3.85	81.8	103.0	-	5748
35	42.7	298	30.5	69.8	41	5.04	3.96	83.1	105.5	-	5981
36	47.2	297	30.7	69.4	26	5.54	4.37	83.5	106.0	-	6633

CALCULATIONS AND MEASUREMENTS.

CALCULATIONS AND MEASUREMENTS

A. - Liquid : Solid Ratios of Samples:

Before shutting down the mill at the end of a test it was essential to determine the liquid : solid ratios of the classifier-overflow and mill-discharge samples in order to be certain that there had been no appreciable discrepancy between the calculated and the actual amounts of water in the circuits concerned. The desired figures were rapidly obtained by substituting in the following formula, taken from Taggart's "Handbook of Ore-Dressing":

$$D = \frac{S - d}{S(d-1)} \text{, where}$$

D = liquid : solid ratio of the pulp,

S = sp. gr. of dry solid in the pulp,

d = sp. gr. of the pulp.

"S" was known and "d" was easily determined by weighing the sample plus bottle, subtracting the weight of the bottle, and dividing by the volume of the sample. The volume of the pulp in the sample was found by adding sufficient water to it to fill the bottle and subtracting this amount from the known total volume of the sample bottle.

B. - Tonnages in the Milling Circuits:

These were determined when making up the assembled data sheets by substituting in the following formula, which is a modified form of one taken from Taggart:

$$S = \frac{C\,(c-s)}{(m-s)} - C, \text{ where}$$

S = dry solids per hr. in the mill discharge, lbs.

C = dry solids per hr. in the classifier overflow, lbs.

c = % of any grade of material in the classifier overflow, found by screen analysis.

s = % of same grade in the return sand.

m = " " " " " " mill discharge.

also, M = C plus S where,

M = dry solids per hr. in the mill discharge, lbs.

The percentage of -200 mesh material was used in all cases when working out the tonnages by means of the above formula. The calculation was checked for each test by substituting in turn, +200, +150 and +100 mesh percentages for the corresponding -200 mesh percentage. In no case was there any appreciable discrepancy between the tonnage figures obtained by using the larger-mesh percentages and those obtained by using the -200 mesh percentage.

C. - Iron Consumption:

The iron consumption per ton of rock ground in the ball mill was determined in two very different ways during the course of the tests:

(a) By chemical analyses of the dry solids in the mill discharge, classifier overflow and return sand.

(b) By weighing the ball charge after certain series of tests.

It was found that the figures obtained by the two methods checked very closely.

D. - Surface Measurement:

Toward the close of the session it was decided that an attempt should be made to obtain some reasonable figure for the actual surface of the -200 mesh material produced during the grinding tests, so that the grinding efficiencies could be calculated in some definite units such as "square centimeters of new surface produced per foot-pound of energy". Figures for the surfaces of all material coarser than -200 mesh were available, but previously the surface of the -200 mesh material (which alone represents by far the greater portion of the energy expended in doing useful work) had been assigned an arbitrary value which was at best quite indefinite and a poor approximation of the truth.

Working with samples of -400 mesh quartz, supplied to the Department of Mining through the courtesy of John Gross of the United States Bureau of Mines, Professor Bell was able to obtain a satisfactory calibration curve for the photoelectric surface-measurement apparatus installed in the mining laboratory. Since the samples obtained from the McGill tests were not pure quartz and were, moreover, -200 mesh size, their surfaces could not be obtained directly from the calibration curve. By drawing a parallel curve through two points established by means of elutriation tests, however, it was possible to determine the surfaces of the McGill samples reasonably well. The figures so obtained will require investigation in the future, but for the purposes of this investigation they may be considered quite satisfactory.

DISCUSSION OF RESULTS.

DISCUSSION OF RESULTS.

Grinding Efficiency:

Considering first the case of the Marcy Quick-Discharge mill vs. the Open-End mill, it would appear, from a study of Tables 3, 4 and 5, that the former is the more efficient. This fact is most evident in Table 4, which gives comparative data of four tests for each mill wherein the variable factor was the feed rate. Not only does the efficiency of the quick-discharge mill greatly exceed that of the open-end mill in every test, but it also appears to be unchanged by increase in feed rate, at least within the range investigated. On the other hand, the efficiency of the open-end mill appears to be at a maximum value with a feed rate of slightly over 500 lbs. per hour, dropping off materially by the time the feed rate has reached 600 lbs. per hour. This seems to indicate that the open-end mill had reached a point of overload at a feed rate of 600 lbs. per hour, a premise that is supported by the fact that the mill was much less noisy during Test 37 than it had ever been previously. The quick-discharge mill is apparently able to do what its makers claim it can do, i.e. handle more material per unit of time than an open-end mill of the same size under the same conditions. In addition, it produces more -200 mesh material (which has greater surface) than the open-end mill.

Regarding the effects of moisture, feed rate and speed of revolution, the following conclusions appear to be justified:

(1) For both quick-discharge and open-end mills, the efficiency drops off with increase in the liquid : solid ratio of the pulp above a moisture content of 30 percent.

(2) For the open-end mill, the efficiency increases with the feed rate up to something over 500 lbs. per hour and then falls off rapidly, while for the quick-discharge mill it apparently is unaffected by feed rate.

(3) For the open-end mill, the efficiency falls off appreciably with an increase in speed from 39.8 r.p.m. to 50.6 r.p.m. (Table 5), while for the quick-discharge mill, it appears to increase slightly with increased speed. In all probability, this apparent increase is due in some measure to experimental error, and the efficiency of the quick-discharge mill is unchanged by increase in speed over the range investigated.

In "Milling Methods", A.I.M.M.E., Vol. 112, p. 94, Fahrenwald gives a tabulation of some results obtained by Gross and Zimmerley comparing the efficiencies, in sq. cm. per ft.-lb., of commercial mills with that of the drop-ball apparatus used by them in crushing tests. Gross and Zimmerley found that the average efficiency of primary and secondary commercial mills was 44.8 percent of that of their drop-ball apparatus. This apparatus produced 240 sq. cm. of new surface per ft.-lb. of energy, therefore the commercial mills averaged 107 sq. cm. per ft.-lb. The average efficiency obtained during the present investigation is, for the open-end mill, 101 sq. cm. per ft.-lb. and for the quick-discharge mill, 110 sq. cm. per ft.-lb. (Table 4). The average of these two figures is 106, therefore it appears that the 3-ft. laboratory mill used in this investigation gave a performance which was practically identical with that of much larger machines. This substantiates, to some extent, the contention of Gow, et al. (29), namely, that their 2-ft. mill gave a performance comparable with that of commercial mills.

Iron Consumption:

As has been previously mentioned, the ball wear was measured directly by counting and weighing the total ball charge from time to time, and indirectly by calculations based on chemical determinations of the amount of iron present in the classifier overflow. The figures obtained by the two methods checked very closely, and they indicated rather an enormous iron consumption. An examination of Tables 3, 4, and 5 shows that an average of approximately 6 lbs. of iron was consumed per ton of rock ground. Of this amount, 3.5 lbs. were lost by the 1.75-in.

balls and 2.5 lbs. by the 1.5-in. balls, which indicates that Davis (12) was correct in his assumption that "the rate at which the weight of any ball decreases in any mill is directly proportional to its weight". The greater wear of the larger balls also indicates that they do more crushing work than the smaller ones, thus supporting Taggart (11), and others in their contentions regarding the effect of ball size on crushing efficiency.

The average ball wear increases with the moisture content in the mill (Table 3), which would be expected since the cushioning effect of the rock particles in the pulp is decreased with decrease in viscosity of the pulp.

Table 4 shows that ball wear decreases with increase in feed rate, which also appears reasonable since the viscosity of the pulp, and consequently the cushioning effect of the solids, is increasing.

Table 5 shows that ball wear increases greatly with speed. The rate of increase in iron consumption is much greater in the quick-discharge than in the open-end mill, which fact offsets, to some extent, the better grinding efficiency of the former. In any mill, however, it seems reasonable to conclude that speeds near to or above the critical will not prove economical because of the high ball consumption; cf. Fahrenwald and Lee, (22).

It was found that an average of 96% of the iron worn from the balls during grinding tests was of -200 mesh size. This indicates a large amount of work uselessly, and in fact, harmfully expended as far as grinding efficiency is concerned.

SUMMARY AND CONCLUSIONS.

SUMMARY AND CONCLUSIONS.

An investigation has been carried out in the field of fine grinding using a 3-ft. Marcy ball mill. The effects on grinding efficiency and ball wear of the feed rate, ball-mill speed and pulp density have been investigated, the pertinent data being compiled in Tables 3, 4 and 5. In all, fifteen grinding tests have been completed, of which six were carried out with the Marcy Quick-Discharge mill and nine with the same mill minus the discharge grid, i.e. with open discharge. As nearly as possible, the factors affecting grinding efficiency were duplicated for each pair of tests, one with the quick-discharge mill and one with the open-end mill, so that the characteristics of the two could be compared.

Surface measurements of the -200 mesh material produced during the tests were successfully made by means of an apparatus of a photoelectric nature, and the efficiencies of the mills worked out in terms of square centimeters of new surface produced per foot-pound of energy expended.

The more important conclusions drawn from the assembled data sheets are as follows:

(1) Under any given grinding conditions, the Marcy Quick-Discharge mill is more efficient than the same mill

with free discharge.

(2) A moisture content of 30% of the mill pulp gives the most efficient grinding for both mills.

(3) Optimum feed rate for the open-end mill is approximately 500 lbs. per hour and the optimum speed 39 r.p.m.

(4) In the case of the quick-discharge mill, both feed rate and speed would appear to have little effect upon the grinding efficiency over the range investigated, namely, 300-600 lbs. per hour and 39.3-47.2 r.p.m., respectively.

(5) The 3-ft. laboratory mill appears to give a grinding performance distinctly comparable to that of large commercial mills.

(6) Iron consumption in small mills is excessively high and is confined almost entirely to the balls. The mill liners appear to be subject to relatively slight wear.

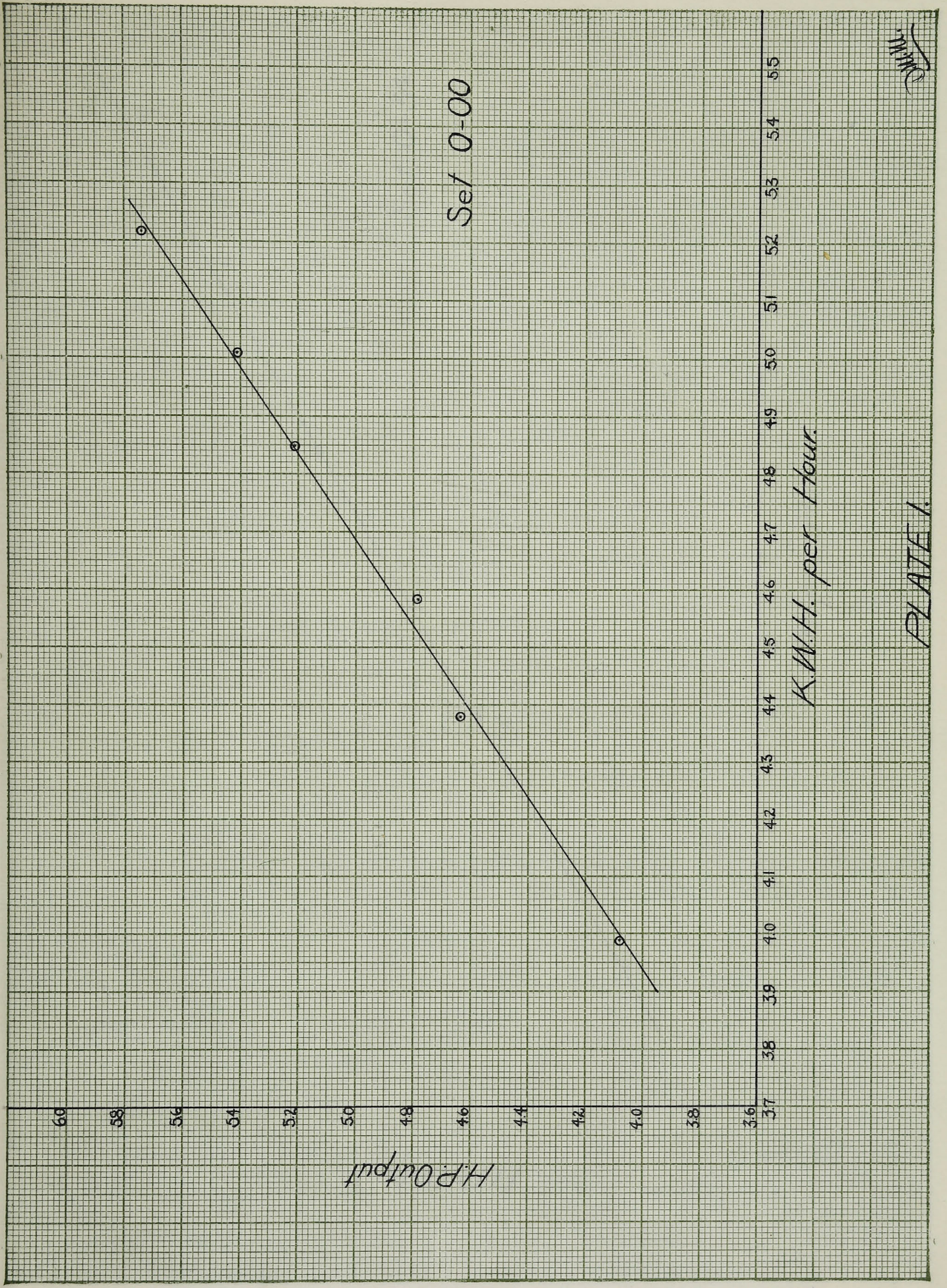
(7) Ball wear is directly proportioned to the weight or diameter of the ball, and is greater in the quick-discharge than in the open-end mill. Ball wear increases with speed and pulp dilution and decreases with increase in feed rate.

(8) It seems reasonably certain that a ball charge consisting of balls of the same diameter will give a more efficient grinding performance than that of a charge of balls of various diameters, providing, of course, that the size of ball used in the first case is capable of crushing the largest piece in the feed.

(9) The iron consumed in grinding quartz and many ores is ejected from the mill largely as -200 mesh material and, as such, represents a large amount of wasted energy.

(10) High-speed ball mills, such as are advocated by Fahrenwald and Lee (22), would appear to be out of the question as far as economical grinding is concerned because of the high iron consumption that would result from their use.

PLATES.


THE HUGHES OWENS CO., LTD.
NO. 404
Set 0-00
K.W.H. per Hour.
H.P. Output
PLATE I.
3.7 3.8 3.9 4.0 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 5.0 5.1 5.2 5.3 5.4 5.5
3.6 3.8 4.0 4.2 4.4 4.6 4.8 5.0 5.2 5.4 5.6 5.8 6.0

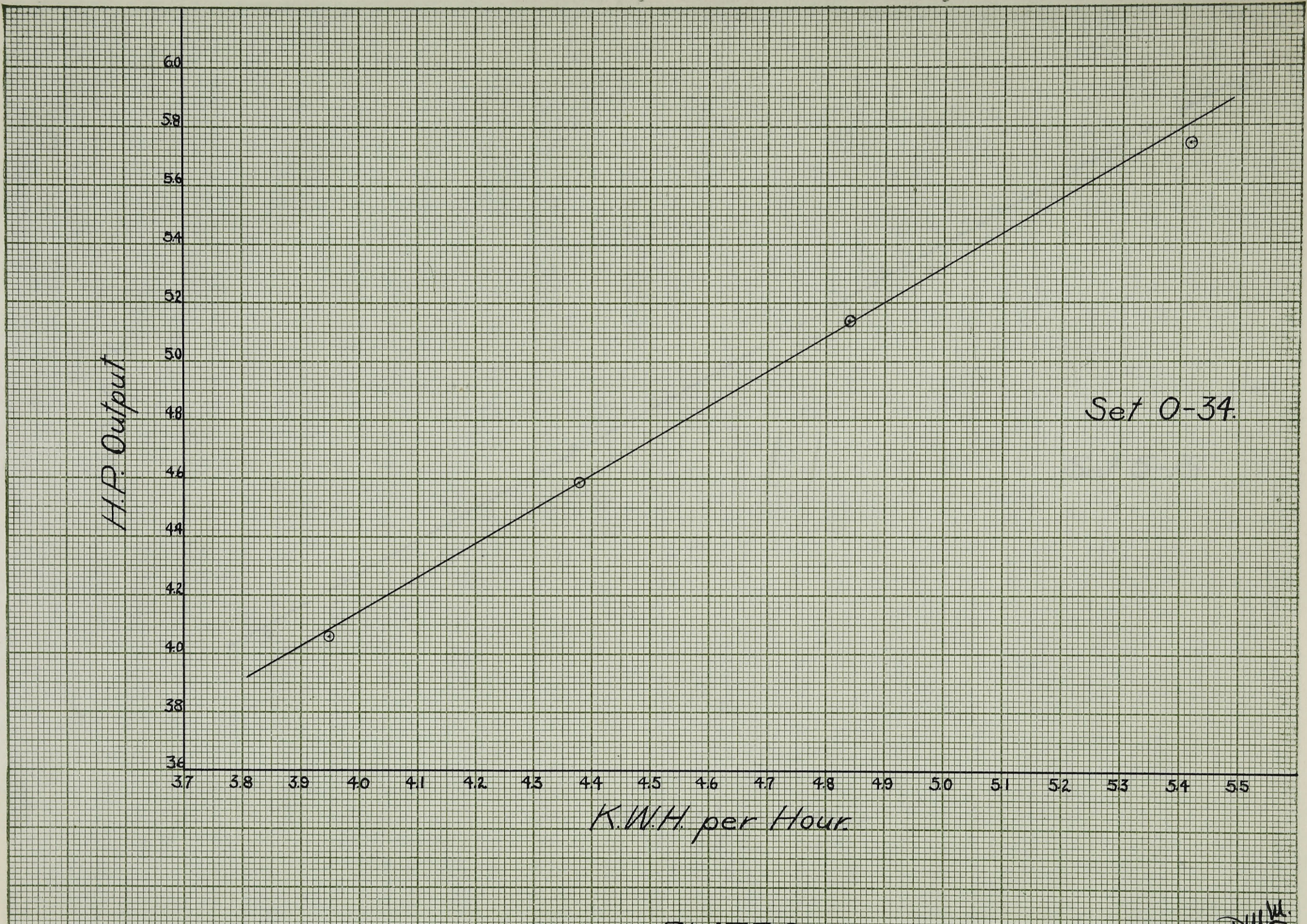

6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
H.P. Output
Set O-34.
3.7
3.8
3.9
4.0
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
4.9
5.0
5.1
5.2
5.3
5.4
5.5
K.W.H. per Hour.

PLATE 2.

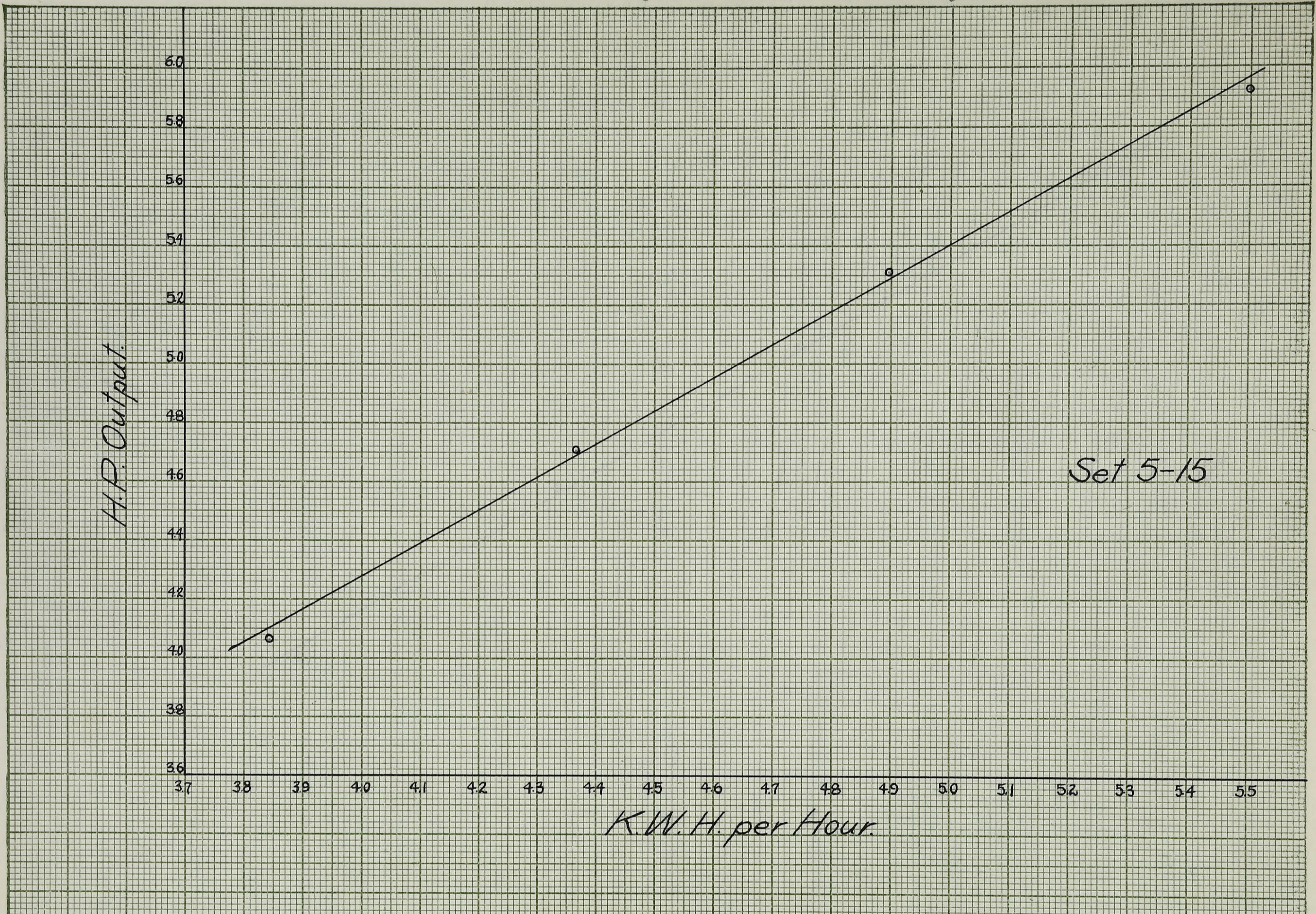

H.P. Output.
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.7
3.8
3.9
4.0
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
4.9
5.0
5.1
5.2
5.3
5.4
5.5
K.W.H. per Hour.
Set 5-15

PLATE 3.

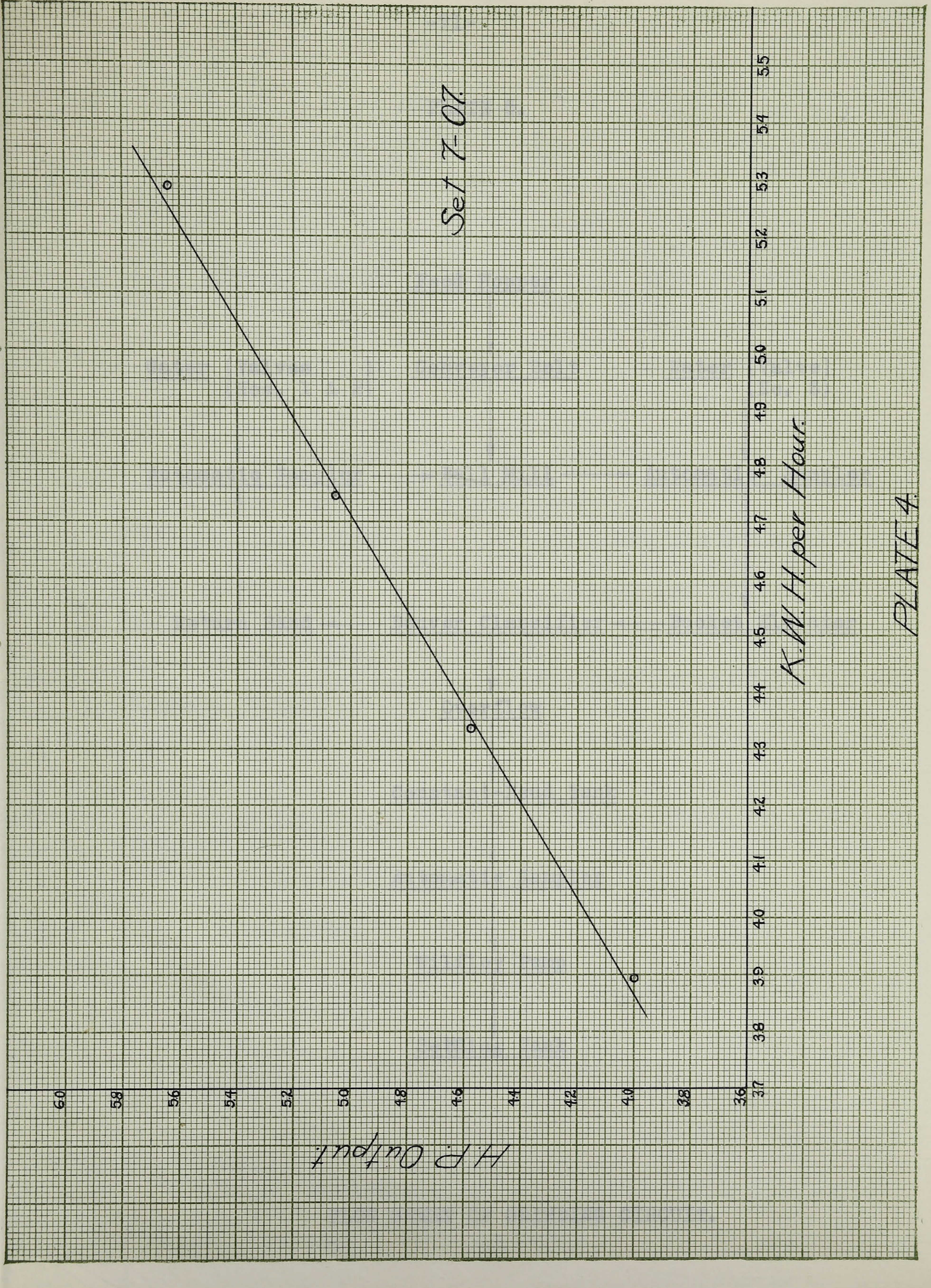
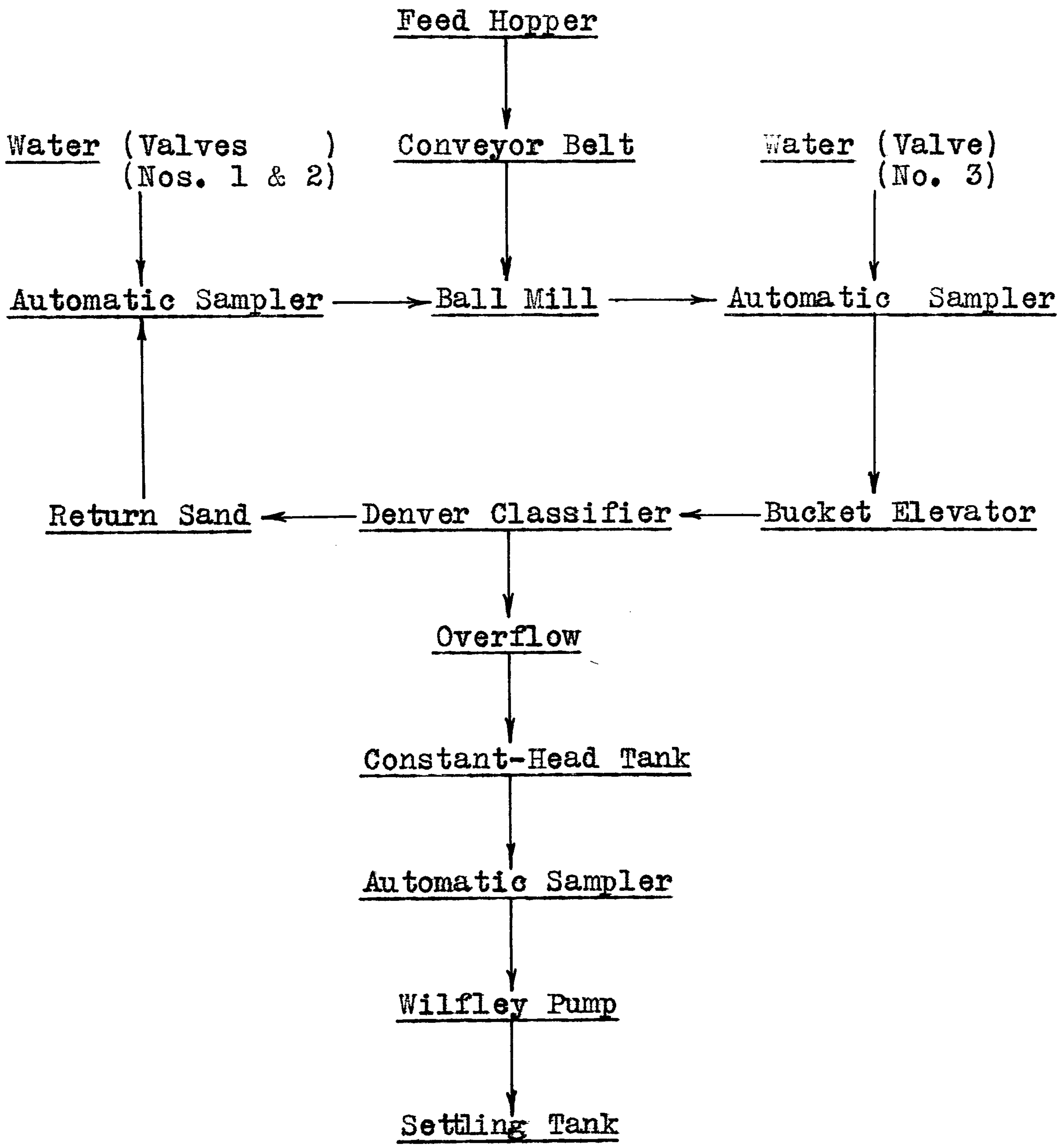
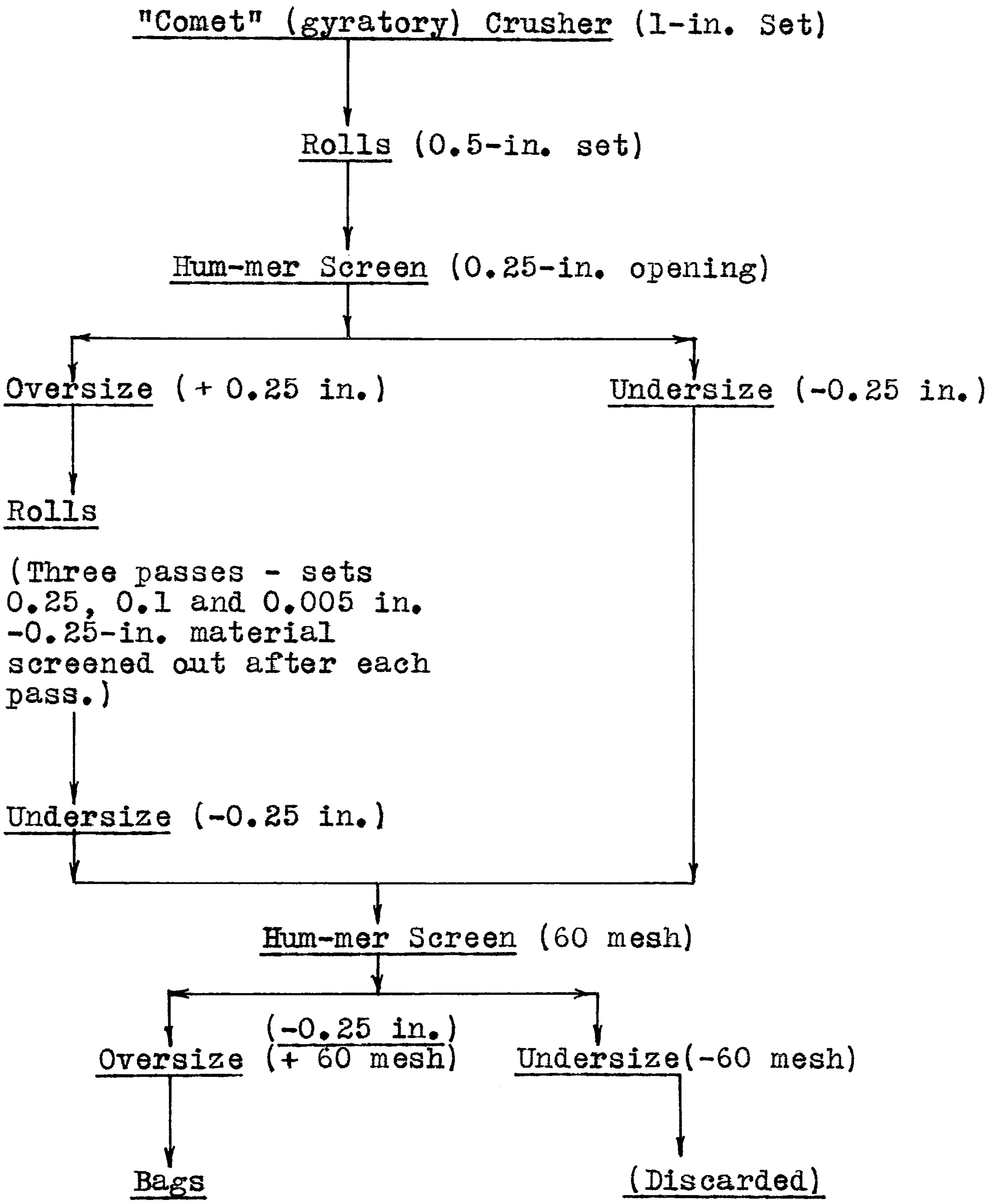

Set 7-07.
K.W.H. per Hour.
H.P. Output
3.7 3.8 3.9 4.0 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 5.0 5.1 5.2 5.3 5.4 5.5
3.6 3.8 4.0 4.2 4.4 4.6 4.8 5.0 5.2 5.4 5.6 5.8 6.0
PLATE 4.

PLATE 5.



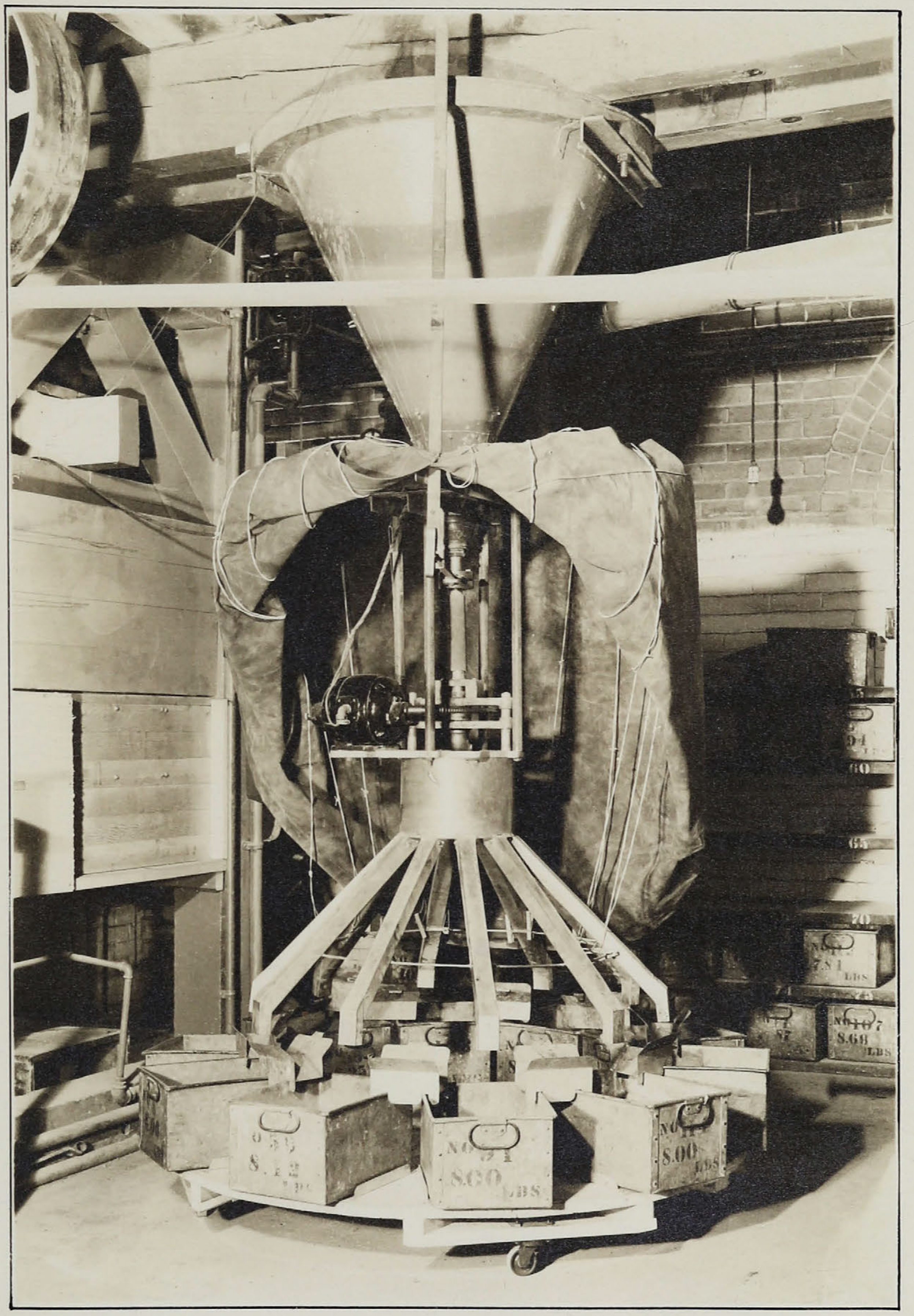
FLOW SHEET OF GRINDING CIRCUIT.

PLATE 6.



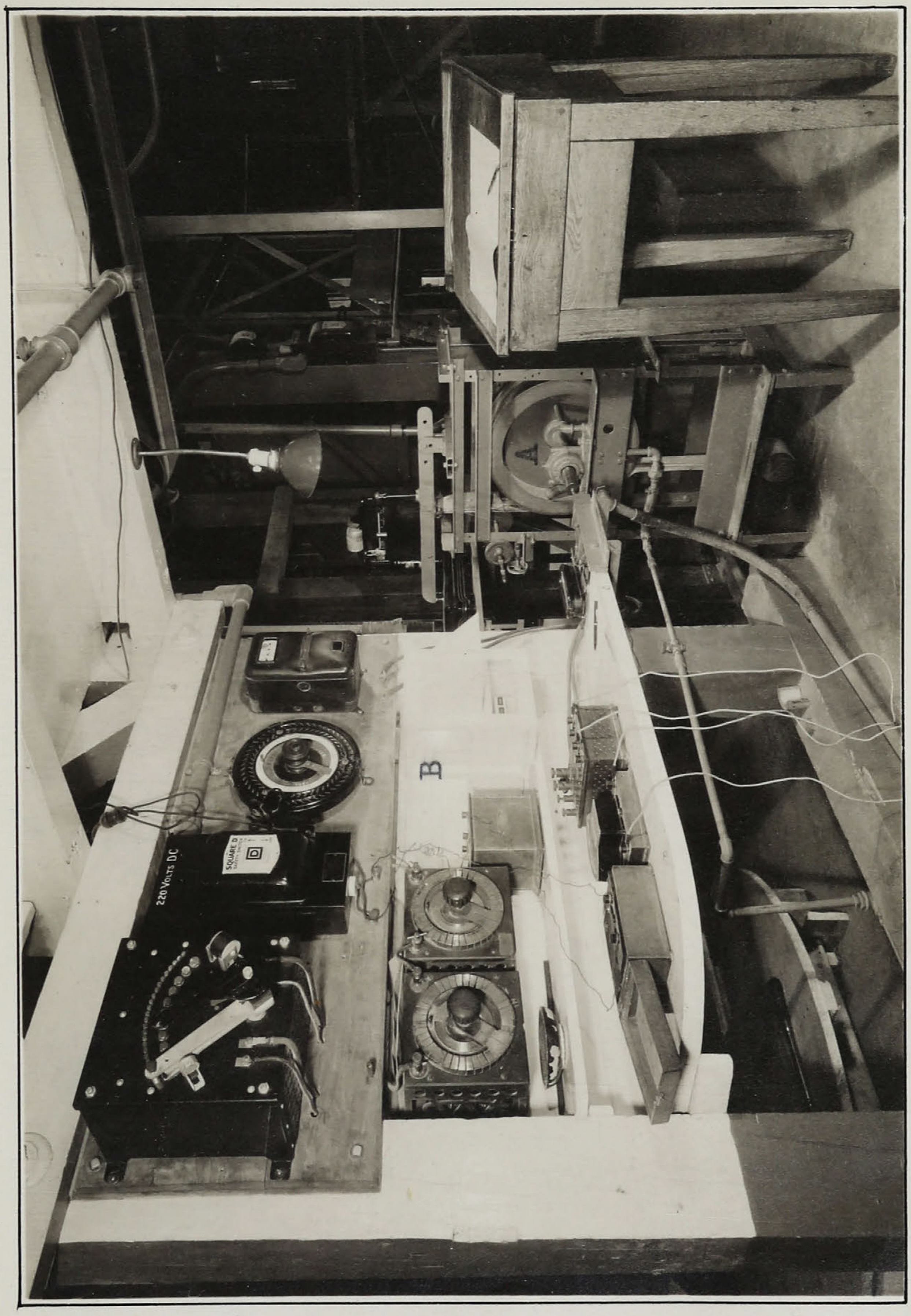
CRUSHING FLOW SHEET.

PHOTOGRAPHS.



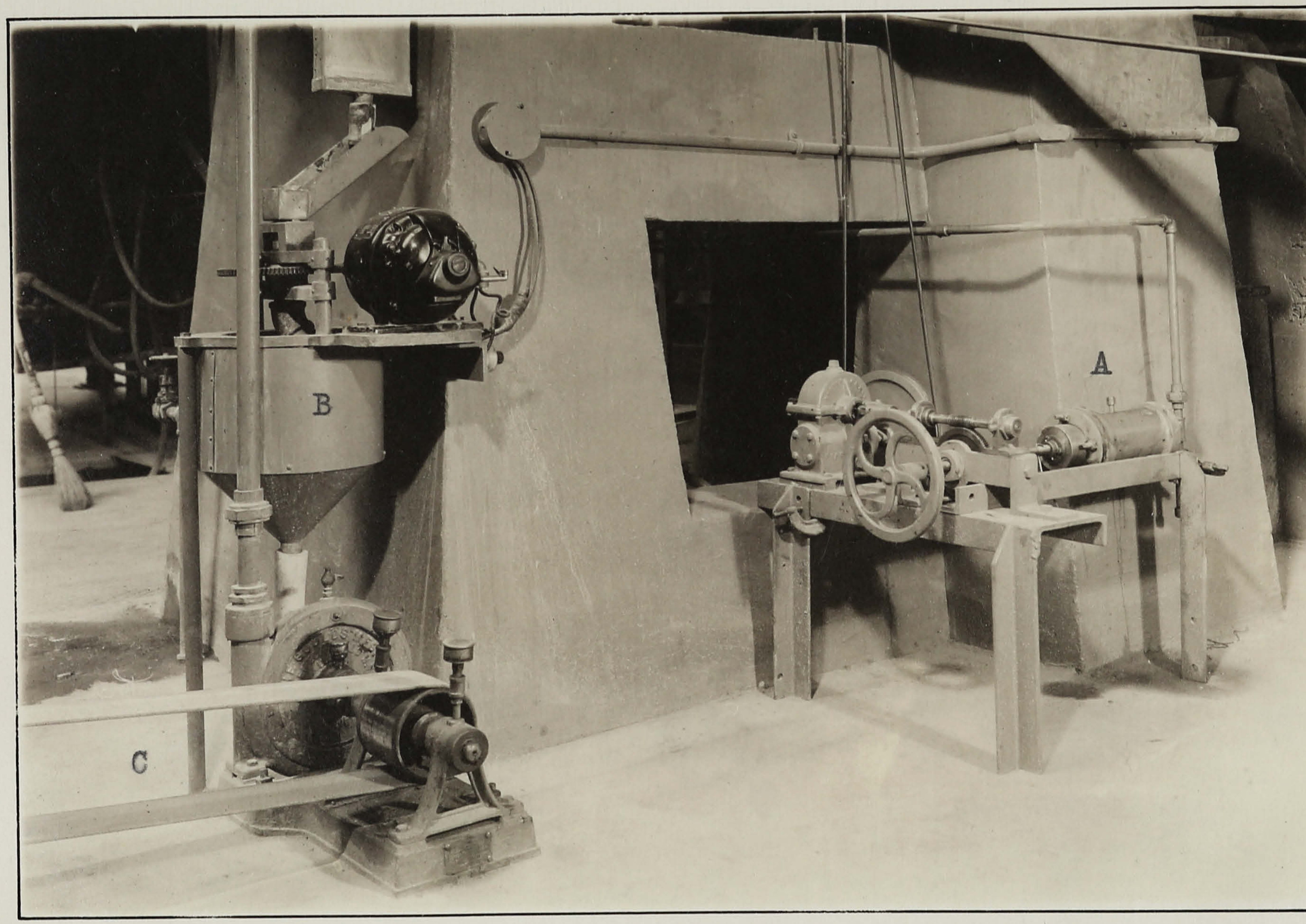
PHOTOGRAPH NO. 1.

THE BELL MIXER.



PHOTOGRAPH NO. 2.

A - BELL BRAKE.
B - CONTROL PANEL.



PHOTOGRAPH NO. 3.

A - AUTOMATIC GREASER.
B - AUTOMATIC SAMPLER.
C - WILFLEY PUMP (Not Used).

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