ON THE EFFICIENCY OF THE TUBE MILL

Subject to revision.] [*A Paper to be discussed at a Meeting of the Institution of Mining and Metallurgy, to be held at the Rooms of the Geological Society, Burlington House, Piccadilly, W., on Thursday, October 19th, 1911, at Eight o'clock p.m.*

The Economics of Tube-Milling.

A report on an investigation for the purpose of determining the most efficient working conditions of the Tube-Mill on metal-bearing ores.

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THE investigation, the results of which are given in this paper, was undertaken by the author as the recipient of the Research Scholarship awarded by the Transvaal Chamber of Mines in 1909, and in part fulfilment of the requirements for the M.Sc. degree of McGill University, Montreal. The work was carried out at McGill University, in the laboratories of the Mining Department, of which Dr. J. Bonsall Porter is the Director.

The treatment of the subject will be taken up in the following order:—

1. Tube-milling in general, showing the growth of the practice up to the present day.
2. The factors governing the efficient working of tube-mills.
3. Tests proposed and tests actually carried out.
4. The general theories of rock crushing.
5. Description of the experimental tube-mill and accessory apparatus employed.
6. Description of a complete test.
7. Data and results of "Feed Tests."
8. ,, ,, "Moisture Tests."
9. ,, ,, "Pebble Load Tests."
10. ,, ,, "Speed Tests."
11. Summary of results, and deductions therefrom.

1. *Tube-milling in general, showing the growth of the practice up to the present day.*—The modern "tube-mill" is a most efficient grinding machine, and is rapidly taking the place of Chilian mills, roller mills, grinding pans, and similar apparatus. Though used for many years as a cement grinder, the first reference found by the author to its use as an ore crushing machine was in the year 1892, when it was used by Dr. Diehl for grinding Kalgoorlie ores. For

diameter of the outlet to the classifier is $2\frac{3}{16}$ in. and its capacity is about 400 tons of sand with 26 % moisture per 24 hours.

At a comparatively early stage in the development of the tube-mill it became evident that high efficiency could only be obtained by feeding a sand containing a minimum of slimes, and by reducing the percentage of water below the 50 % first taken as a standard. This demand has resulted in the invention of a number of classifiers and thick pulp feeds, of which the "Caldecott diaphragm cone," mentioned above, is the most satisfactory. Up to the present, however, no efficient means has been found for providing an exactly uniform mixture of coarse and fine sands in the mill feed. The diversion of the fine ore from the bins directly to the tube-mill, without passing it through the battery, is one of the strongest propositions put forward for increasing the efficiency of the stamp-tube-mill combination, and a start in this direction has already been made, with satisfactory results. It is remarkable to what a great extent fine battery crushing has given way to coarse, and it is possible that stamps may ultimately be superseded by other types of coarse crushers when the ore is to be finally crushed in tube-mills.

2. *The factors governing the efficient working of the Tube-mill.*—There are two kinds of crushing which take place inside a mill:—

(*a*) Crushing by shock, due to the impact of pebbles.

(*b*) Crushing by abrasion, due to the rolling and rubbing of the pebbles, and contact with the lining of the mill.

One form of crushing or the other will predominate, according to the type of mill used, the pebble load, and other conditions.

Although the consideration of the tube-mill from a mechanical point of view is fairly straightforward, much experience is necessary in order to get the best results from it. For this reason attempts have been made to determine the most economical conditions under which tube-mills can be used, taking into consideration the desired fine grinding as the end to be obtained with the least consumption of power and smallest wear on pebbles and lining. These three points seem to depend on the following four factors:—

1. The pebble load.
2. The tonnage dealt with, and the character of the sand.
3. The thickness of pulp, *i.e.* the amount of water carried by the sand.
4. The diameter of the mill and the number of revolutions.

A change in any one of the above will cause a change in two, and sometimes all three of the points given.

The investigation of these interesting points is obviously desirable, and the subject was an eminently suitable one to be undertaken by a laboratory such as that possessed by McGill University, owing to the freedom from interference with continuous tests which would be inevitable on ordinary commercial plants.

The rock chosen to be experimented on was an elæolite or nepheline syenite, of a hard uniform character, composed essentially of orthoclase, elæolite and horneblende (cf. Appendix) and was obtained from the Outremont Quarries, Montreal. This rock was used as it was considered to be typical of a hard compact ore.

3. *Tests proposed and tests actually carried out.*—Four investigations were decided on, as follows:—

Series I.—In which the feed was to be varied, the moisture, pebble load and rev. per min. remaining constant.

Series II.—In which the moisture was to be varied.
Series III.— ,, ,, pebble load ,,
Series IV.— ,, ,, ,, speed ,,
the other three factors remaining constant in each case. These are given under sections 7–10.

Owing to doubt as to the possibility of carrying on so extensive an investigation as is above outlined, it was originally intended that only nine tests in all should be carried out, three each in Series I, II and III; it was afterwards, however, found possible to carry out six on Series I, four on Series II, three on Series III, and four on Series IV, making a total of seventeen tests.

It was hoped that the results of these tests would clearly show the most economical conditions for the running of the particular mill in the laboratory, and that fresh light might be cast on the whole matter of tube-milling. As will be shown later, the results seem to have justified the expectations.

The actual preparation of the rock for the investigation involved a considerable amount of labour and time, it having first to be selected at the quarries, transported to the college, packed, sledged and crushed to $1\frac{1}{4}$ in. in a "Comet" crusher. 14 tons of it had next to be crushed through a screen having 18 holes to the lin. in. in a 5-stamp battery, de-slimed in a classifier, and the sands dried, weighed and stored.

4. *The general theories of rock crushing.*—Standard work on this subject has been carried out by Von Reytt and Argall, while among the more modern theories the best known are as follows:—

(*a*) The suggestion of Messrs. Pearce and Caldecott, who propose the representation of the efficiency factor by the reciprocals of the diameter of the particles.*

(b) The theory of Messrs. Klug and Taylor that the efficiency factor should be represented by the squares of the diameters.†

(c) The proposal of Mr. R. W. Chapman, who suggests as the efficiency factor the number of mesh per lin. in. of any set of screens, with a constant ratio between diameter of wire and mesh aperture, *i.e.* I.M.M. Standard screens.‡

These theories are all based on Rittinger's theory, which states that the work done in crushing is proportional to the amount of new surface produced. As this theory is generally recognised to be only approximately accurate for coarse crushing, and inaccurate for fine, they have all a common weakness, which would of course be more prominent in comparative tests between fine and coarse grinding appliances than on a single machine giving only a small range of grades. On account of this, great interest was aroused among the leaders of the mining and metallurgical professions when a proposal was brought forward by Mr. H. Stadler that the only accurate method of determining the energy absorbed would be one based on "Kick's Law," the kernel of which is "that the energy absorbed in crushing is proportional to the reduction in volume," the volume or weight of the particles thus being the true basis for establishing the relative values of the work done.

The following is a short résumé of Mr. Stadler's paper on "Grading Analyses and their application."§

During some recent experimental work conducted by him on behalf of the "Mines Trials Committee" in the Transvaal, he found it necessary to establish a slightly different ratio to that adopted by the Institute of Mining and Metallurgy in their standard table of laboratory screens.

He adopted a geometrical series in which the ratio between the sizes of the apertures in successive grades was the cube root of two = $\sqrt[3]{2}$, the first term being 1 in., the second 0·794 in. and so on; by this means a grading is secured which is equivalent to a successive reduction by one-half of the volume (or weight) of the particles. Thus, by reducing the cube of the unit successively by one-half of its volume and assuming these fractures to be again of cubical shape, each size of this series of theoretical cubes obtained represents a grade of a reduction scale of the ratio 2.

* *Jl. of Chem., Met. & Min. Soc. of S.A.*, September, 1906, March, 1907.

† *Jl. of the Chamber of Mines*, January 31st, 1906.

‡ *Proceedings Australasian Inst. of Min. Eng.*, October, 1909.

§ *Trans.* xix, pp. 471–485.

To prove that the functions of the irregularly shaped average particles* determined by two consecutive screens vary in the same way as the grades of the theoretical cubes, he carried out a series of nine tests on Rand ore, using grades from 1 in. down to 30 mesh (0·0166 in. aperture), and found that the ratio of decrease in weight of the particles of each grade corresponded remarkably well with the correct reduction scale of the theoretical cubes, the average ratio of the theoretical results being 62 %.

In the explanation of his method for obtaining an exact expression of the efficiency of the crushing operation for comparative purposes, he uses the following definitions :—

The force required to cause a fracture is represented by the area of fracture over which the cohesion of the molecules has to be destroyed, multiplied by a co-efficient representing the resistance which the molecules offer to their separation.

In order to perform mechanical work this force has to run through a distance which is represented by the amount of deformation the body can stand before reaching the breaking point.

Hence the mechanical work done is the product of the force into the distance; but since, in a regular scale of reduction by volume, the diameters of the particles decrease in the same ratio as the area of fracture increases, the mechanical work necessary for reducing the volume (or weight) of the unit from one grade to the next one following is a constant for each grade, and is called the crushing or energy unit, denoted by the term E.U.

The ordinal numbers of any arithmetical progression given to these grades represent consequently the relative values of the energy which has to be spent upon producing this respective grade from the initial unit. This number is, therefore, called the "mechanical value" of the grade.

For obtaining the mechanical value of the mixed sands, the percentages of the grading are simply multiplied by the number of the energy units for the respective grade, and the products added.

The "useful work done per unit" by any crushing machine is determined by the difference between the mechanical values of the samples taken from the inlet and discharge ends of the machines, and for obtaining the total work done this difference has to be multiplied by the tonnage dealt with.

Finally the relative mechanical "efficiency" is the value obtained by dividing the total work done by the horse-power consumed.

By means of this method, it is claimed that it is now possible to

* Experiments carried out on the nepheline syenite show an average ratio of 72 %.

determine with a high degree of accuracy the relative merits of different crushing appliances, or the mechanical efficiency of one and the same machine working under varying conditions.

In practice this method has so far given great satisfaction, and there is no denying that for laboratory purposes it supplies a long-felt want.

As the method is based on "Kick's Law," it would not now be out of place to give the chief argument used for and against Stadler's use of this law.

Kick's law states that: "The energy required for producing analogous changes of configuration of geometrically similar bodies of equal technological state, varies as the volume or weights of these bodies."

Several scientists have taken exception to the term "of equal technological state," maintaining that the average conditions of ore in general do not agree sufficiently with the premises of "Kick's Law" to justify its application in practice.

Stadler, in his interesting reply* to the discussion on his paper, maintains that, though perfectly homogeneous materials do not exist, the definition "of equal technological state" is broader; since as long as the physical peculiarities of particles in different stages are identical, irregularities of material would be admitted; similarly, if a conglomerate of hard and soft components were taken, although the softer material would crush first, being reduced more rapidly in size, it would find its way into the spaces between the coarse particles, thus escaping crushing, until the coarse particles were further reduced.

When one remembers that there are over four millions of particles of the size of the 80 mesh I.M.M. in a cubic inch of material, some idea of the averaging which takes place during crushing is obtained.

With the above facts in mind it will at once be seen how extremely advantageous such a method is for laboratory use, and it was unanimously decided that it would be applied to all crushing tests carried out in the mining laboratory of McGill University.

Screens.—The screens used in the various McGill tests were the standard set brought out by the I.M.M. in London, as although their mesh apertures do not follow the same curve of seriation as Stadler's theoretical apertures, it was found possible to pick out a restricted set with apertures corresponding fairly well to his mathematically correct scale, and complying at the same time with the requirements of equality of steps from grade to grade in regard

* *Trans. Inst. M.M.*, *Bull.* 75, and *Jl. of Chem., Met. & Min. Soc. of S.A.*, December 1st, 1910.

TABLE I.

Grading Analysis.		Ordinal No. or Mesh Value.			
		Stadler's Standard Grades.		Nearest I.M.M. Screen.	
I.M.M. Mesh. Per Lin. in.	Weights. %.	Per grade. E.U.	Total. E.U.	Per grade. E.U.	Total. E.U.
	20	13	2·60	13·00	2·60
12		14		13·81	
	12	15	1·80	14·92	1·79
20		16		16·02	
	10	17	1·70	16·91	1·69
30		18		17·80	
	12	19	2·28	18·90	2·27
50		20		20·00	
	11	21	2·31	21·04	2·31
80		22		22·08	
	2	23	0·46	22·93	0·46
120		24		23·77	
	4	25	1·00	24·40	0·98
200		26		26·02	
	29	28	8·12	28·00	8·12
	100·0		20·27		20·22

to the reduction in volume. The adoption of this series of screens has the added advantage of bringing this investigation in line with the efforts of the I.M.M., whose standard screens represent not only the best and most accurate manufacture as yet produced, but also form a graded series which it is the Institution's desire to make standard throughout the world.

Although the values of Stadler's standard grades are not identical with the corresponding I.M.M. screens, yet the difference is so slight that the former may be taken without in any way interfering with the accuracy of the results. How carefully the values compound is shown by Table I above.

The list of standard laboratory screens used is given below in Table II.

TABLE II.

Original number or mesh value of (E.U.) Grade.	No. of Mesh. Lin. in.	Mesh Aperture. Lin. in.	Diam. of Wire.	Area of Discharge.
15	20	·025	·025	25·0
17	30	·0166	·0167	24·8
19	50	·01	·01	25·0
21	80	·0062	·0068	24·6
23	120	·0042	·0041	25·4
25	200*	·0030	·002	25·0
28	–200 Grade			

5. *Description of the Tube-mill and accessory apparatus.*—The mill used in the tests was of the trunnion type, and was formerly an old chlorination barrel. The outside dimensions were: length, 4 ft. 8 in.; diam., 3 ft. 5 in.; inside dimensions with liner in, were: length, 3 ft. 6 in.; diam., 2 ft. 10 in. The tube shell was formed of $\frac{3}{8}$-in. steel, bolted to the cast iron end pieces, 2 in. thick, which were stiffened by six 2-in. ribs. The lining of the mill consisted of 8 in. by 4 in. by $2\frac{1}{2}$ in. Silex bricks, set in patent cement. At the discharge end of the mill was an iron screen perforated with $\frac{3}{4}$-in. holes. This prevented chips of the flint pebbles from being discharged with the pulp. 18-mesh sand was delivered by means of a pipe from the bucket elevator to the cone, the size of the discharge orifice being altered by screwing on caps with different sized apertures. These caps were all previously calibrated by weighing the amount of sand flowing through them in certain fixed periods. The water from a tank under constant head entered a trough, the flow being regulated by means of a cock and indicator, the cock having been previously carefully calibrated. The pulp was discharged, and after being

* Screen manufactured by W. S. Tyler & Co., Ohio.

sampled was wasted, as there was no further use for it. The pebbles were charged into the mill through a manhole, 15 in. by $10\frac{3}{4}$ in., around the door being a flanged collar of $\frac{3}{8}$-in. steel, serving as a bearing for the $\frac{3}{8}$-in. steel plate which acted as a lining at this point. The plate was held in place by tightening the nuts on the two bolts which protruded through the cast iron cover-plate, fitted on the outside of the tube. The barrel revolved on hollow trunnions, and was driven, by a chain and sprocket gearing, from the stamp-mill countershaft, which was in turn driven by a 15 hp. motor.

A D.C. motor was used, its output being 15 hp. at 835 rev. per min. The electrical instruments used for power measurements were a D.C. voltmeter and ammeter, and a wattmeter.

The preliminary crushers necessary were :—

1. Sledge.
2. A "Comet" crusher.
3. Five-stamp battery, each stamp weighing 600 lb., the total crushing capacity being 800 lb. per hour.

The screens used for the grading analyses were 8 in. in diam., and were mounted on nested circular copper boxes 2 in. deep, fitted to a screening machine.

This machine was built in the shop of the Mining Department, from drawings based on a description and illustration given in a paper* by Mr. T. J. Hoover, but the apparatus is not exactly similar although the principle is the same. The mechanism of the screening machine is very simple. In the original design only two springs were thought to be necessary, but it was found that such a rhythmic motion was set up between them, that they were always liable to wind themselves around the machine; by introducing a third spring, loosely attached at right angles to the other two, this motion was effectively broken up. It is claimed by Hoover that a complete analysis can be carried out with this machine in twenty minutes, but, after a series of tests the author found this was quite impossible, the minimum time taken for a satisfactory analysis being 30 minutes, and this only when the 200-mesh screen was tapped at frequent intervals to prevent it from blinding. This period was therefore adopted as the standard time for the 140 screen analyses which had to be carried out.

6. *Description of a complete test. Mill run.*—The amount of material used for each test varied between 800 lb. and 2000 lb.

Before the start of every test the sand was first screened through an $\frac{1}{8}$-in. screen to remove all foreign matter which might possibly

* *Trans.* xix, p. 506.

block up the cone orifice, and the required quantity carefully weighed. The moisture was then measured and regulated to ensure the pulp entering the mill in the required proportions. The theoretical rate of feed of the orifice of the cone was already known through calibration, but it was always checked by weighing the sand remaining at the end of the run. In all cases these corresponded remarkably well, the difference never being more than 9–10 lb. per hour. The moisture was checked after each test, and care was taken to keep the head of water in the tank constant.

The motor was first run light for a few minutes to enable the power consumed by the shafting, belting, etc., to be ascertained, and then at a given signal the mill was started, and the feed and moisture turned on. Power readings were taken at intervals of two and three minutes alternately, care being taken that a power reading was taken simultaneously with a sample. An observer was constantly on the watch at the intake end of the mill to guard against any stoppage of the feed. At the conclusion of the test the feed and water were turned off and the mill stopped, power readings being again taken of the motor and shafting running light.

The rate of flow of water and sand was found to be so regular that it was unnecessary to take systematic moisture samples from the discharge. The speed of the mill was checked several times during each test.

Method of Sampling.—Before the start of these tests great anxiety was felt as to how long the mill would take to assume its uniform conditions, and what feed, moisture, pebble load and speed it would require, the first of these factors being, of course, the most important on account of the comparatively small stock of prepared sand available for use. It was therefore resolved that samples should be taken every five minutes so that their screen analyses, together with their respective power readings, would clearly show how long the mill took to reach a uniform state. This was done, and the results of every one of the tests carried out proved in a most convincing manner that the mill took only 30–35 minutes to assume its uniform conditions. Samples of the sand feed were also constantly taken, and at the end of the test combined into two large samples, each of which was subjected to screen analysis, and the mean result taken as representative of the sand used.

After a sufficient number of tests had been run to make it clear that a 30 minutes' run could be relied upon to give uniformity, the practice of sampling the discharge was changed, and no samples were taken until 35 minutes had elapsed from the start of the test.

The actual length of the tests varied from 45 minutes to 1 hour, as it was found that this period was of sufficient duration to give the data required.

Screen Analyses.—The samples were first decanted and then dried, bagged and ticketed. Each sample in turn was next mixed thoroughly, sampled on the riffle plate, and a quantity of 200 grm. accurately weighed out and screen analysed in the "screening" machine for a period of 30 minutes. Each screen at the conclusion of the run was taken individually, carefully brushed, and its product weighed and mechanical value calculated. The method of first washing the fines through the 200-mesh screen, drying and screen analysing the oversize was tried, but so little difference was found in comparison with the dry method that it was decided to employ dry screening throughout. The screening machine proved a great boon, for the total time for each screen analysis, including preparation and weighing, averaged only 40 minutes, against about 1½ hours by the "hand method."

In addition to this, and of even greater importance, is the fact that all tests on the machine are strictly comparable, whereas hand work is bound to be variable in spite of every effort of the experimenter to use the same force and rate of shaking throughout.

SERIES I.

7. *Data and results of Feed Tests.*—In the first series of tests the rate of feed was varied, and the other factors of moisture, speed and pebble load were maintained at a constant figure.

SUMMARY OF TESTS.

Test.	Feed per 24 hours.	Pebble Load.	Moisture.	Rev. per Min.	Horse-power.	Work done per unit.	Relative Mechanical Efficiency per hp.
	Tons.	lb.	%				
P.	7·2	1200	38	41	6·3	3·89	4·45
C.	9·6	1200	38	41	5·0	3·36	6·45
*B.	12·6	1200	38	41	5·1	2·82	7·02
O.	14·4	1200	38	41	5·6	2·91	7·48
*†A.	18·6	1200	38	41	5·8	2·58	8·29
R.	23·0	1200	38	41	6·6	2·09	7·28

* Data computed from "moisture-efficiency" curve (Fig. 3, p. 28).

† Most efficient feed

CRUSHING EFFICIENCY.

Test.	Feed per 24 hours.	No. of tons crushed to "−120 grade" per 24 hours.	Percentage of Total Feed.
	Tons.		
P.	7·2	2·27	31·5
C.	9·6	2·54	26·5
B.	12·6	2·95	23·5
O.	14·4	3·31	23·0
*A.	18·6	3·96	21·3
R.	23·0	3·79	16·5

In all the following discussions the term "efficiency" is used for the relative mechanical efficiency per hp.

In the above series of tests, shown in Fig. 2, six different feeds were experimented on, varying in amount from 7·2 tons to 23 tons per 24 hours. In the case of four of them, the moisture was kept constant at 38 %. In the fifth, Test "B," it dropped to 37·7 %, whilst Test "A" was run with 33 %.

As it was necessary to bring the two latter tests into line with the former for comparative purposes, the "moisture efficiency" curves (Fig. 3, Series II) were examined to see if this were possible.

It was found that with a feed of 12·6 tons per 24 hours, the efficiency, with 33 % moisture, was 6·66, whereas with 38 % it was 7·02, a difference of 0·36. With a feed of 18·6 tons per 24 hours the efficiency was 7·76, with a moisture of 33 % (Test "A"). Assuming that the moisture efficiency curve † would be of the same character as that obtained for the smaller feed, the efficiency for 38 % moisture was found to be 8·29 by a simple proportion calculation, as follows:—

$$12{\cdot}6 : 18{\cdot}6 :: 0{\cdot}36 : x \therefore x = 0{\cdot}53.$$

Hence efficiency = 7·76 and 0·53 = 8·29.

The hp. was calculated similarly by applying the same value to the "moisture power" curve.‡

The data for Test "B" were deduced directly from the curves.

* Most efficient feed. Data obtained from "crushing-efficiency" feed curve (Fig. 2. p. 16).

† Fig. B, Series II.

‡ Fig. 5, Series II, p. 35.

On examining Fig. 1 it will be seen how well the point (A) conforms to the curve, and, as the curve was drawn originally without the use of this point, the result indicates that this method of deducing data for one test from curves of another is of more than passing interest.

Taking the summary of tests in conjunction with Fig. 1, it seems exceedingly probable that the most efficient feed has been found, above which the efficiency rapidly decreases.

Starting with the small feed, the efficiency is only 4·45, but gradually increases until at the point *m* it is at a maximum, indicating that the best feed is one of 18 tons per 24 hours, with

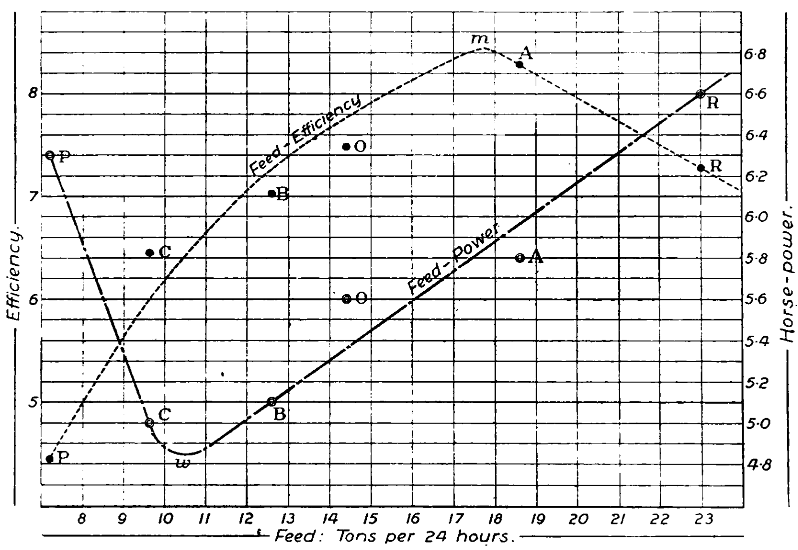
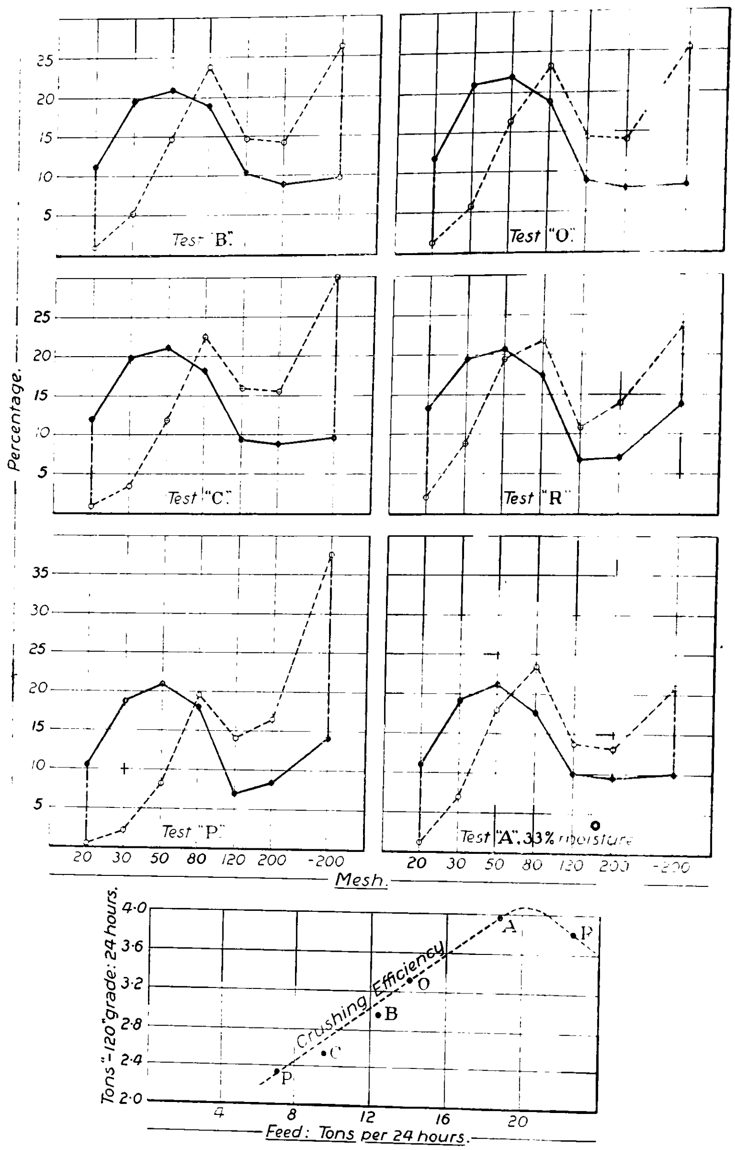


FIG. 1.

an efficiency of 8·05; beyond this point the efficiency drops until with a feed of 23 tons per 24 hours it is equal to 7·28.

Taking now the feed-power curve, it will be seen that the power is relatively high with a small feed, but drops rapidly until it is at a minimum at point *w*, indicating that a feed of 10·5 tons per 24 hours would require the least power of all; beyond this point it gradually increases, following practically a straight line. It will again be noticed how relatively close point A falls to the curve.

Examining next Table II, crushing results, with appended "crushing diagrams," Fig. 2, it is interesting to note that the net output of "–120 grade" per 24 hours gradually increases with the feed. Between points O and R, however, there is only an



Test "B".
Test "O".
Test "C".
Test "R".
Test "P".
Test "A". 3·3% moisture
Percentage.
Mesh.
20 30 50 80 120 200 -200
Crushing Efficiency
Tons "-120" grade: 24 hours.
Feed: Tons per 24 hours.

FIG. 2.

increase of 0·46 tons of "−120 grade," this apparently showing that the most efficient feed will lie somewhat between these two points. The probable curve was drawn (Fig. 2), and from it the data for Test "A" taken. The curve apparently shows that the best crushing efficiency, *i.e.* highest net output of "−120 grade," will be given by a feed in the neighbourhood of 20 tons per 24 hours.

The crushing diagrams were obtained from the average screen analyses of the inlet and discharge samples of each test taken after the mill had assumed its uniform conditions. The black outline is obtained from the average screen analyses of the intake, the dotted from the discharge.

The abscissa of the diagram was first plotted with Energy Units, and the corresponding mesh then substituted, *e.g.* 20 mesh for 15 E.U., 80 mesh for 17, and so on.

These diagrams show extremely well how uniform was the sand used, and the changing point of the decrease of "−80" to the increase of "+80" product occupies practically the same position on each of the diagrams.

In experiments carried out by Mr. H. W. Fox at the Colorado plant of the United States Reduction and Refining Co., he found that above the most efficient feed the fine grinding gradually decreased, the power, however, decreasing also.*

It seems probable, therefore, that if further tests had been carried out by the author with heavier feeds, the grinding efficiency would have continued decreasing, but the power curve would have started to droop.

It is somewhat difficult to compare these tests with those of Fox as he experienced great difficulty in keeping his moisture constant, it varying as much as 8 % in two consecutive tests. As this has been proved to make a great difference in the efficiency of the mill, only a rough comparison is possible.

* *Mines and Minerals*, vol. xxviii, p. 237.

TEST "B." (FIG 2.)

Feed .... 12·6 tons per 24 hrs.
Moisture........................ 37·7 %.
Pebbles .... 1200 lb.
Rev. per min.................... 41.
Length of Test .... 60 minutes.

Remarks.	Time.	Amperes.	Volts.	Watts.
Running Light	—	27	108	2916
Mill on. Starting Torque...	12.00	100	106	10812
	—	63	106	6678
Start of Test	12.02	62	106	6572
	12.05	61	106	6466
	12.07	61	106	6466
Sample B1 taken...............	12.10	61	106	6466
	12.12	61	106	6466
,, B2 ,, ...	12.15	61	106	6466
	12.17	61	106	6466
,, B3 ,, ...	12.20	61	106	6466
	12.22	61	106	6466
,, B4 ,, ...	12.25	62	106	6572
	12.27	62	106	6572
,, B5 ,, ...	12.30	62	106	6572
	12.32	62	106	6572
,, B6 ,, *	12.35	63	106	6678
	12.37	63	106	6678
,, B7 ,, ...	12.40	62	106	6572
	12.42	63	106	6678
,, B8 ,, ...	12.45	63	106	6678
	12.47	64	106	6784
,, B9 ,, ...	12.50	64	106	6784
	12.52	64	106	6784
,, B10 ,, ...	12.55	63	106	6678
	12.57	63	106	6678
Test ended	1.00	64	106	6784
Running Light	—	29	110	3190
	—	29	110	3190

* Mill assumes uniform conditions.

GRADING ANALYSES.

Screen.	Intake.		Discharge.					
	Ba.	Bb.	B 1.	B 2.	B 3.	B 4.	B 5.	B 6.
20	11·00	11·75	1·00	0·75	0·75	0·75	0·75	0·75
30	19·50	20·00	5·50	5·00	5·75	4·75	5·50	4·50
50	21·00	21·25	17·75	16·25	16·75	16·25	17·50	15·00
80	19.00	18·50	25·25	23·75	24·25	24·25	24·00	23·75
120	10·50	10·25	14·00	14·25	14·25	14·50	14·00	15·00
200	9·25	8·75	15·50	13·50	13·25	13·50	13·00	15·00
–200	9·75	9·50	21·00	26·25	24·75	25·75	25·00	26·00
Loss correction	—	—	—	0·25	0·25	0·25	0·25	—
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

MECHANICAL VALUES.

Screen.	Intake.			Discharge.					
	Mech'l. Value of Mean Grade.	Ba.	Bb.	B 1.	B 2.	B 3.	B 4.	B 5.	B 6.
20......	15	1·65	1·77	0·15	0·11	0·11	0·11	0·11	0·11
30......	17	3·32	3·40	0·93	0·85	0·98	0·81	0·93	0·77
50......	19	3·99	4·04	3·38	3·09	3·18	3·09	3·33	2·85
80......	21	3·99	3·98	5·30	4·98	5·09	5·09	4·98	4·93
120......	23	2·42	2·36	3·22	3·28	3·28	3·34	3·22	3·45
200......	25	2·32	2·19	3·88	3·38	3·31	3·38	3·15	3·75
–200......	28	2·73	2·66	5·88	7·35	6·93	7·21	7·00	7·28
Loss correction	—	—	—	—	0·06	0·06	0·06	0·06	—
Mechanical value of sample		20·42	20·40	22·74	23·10	22·94	23·09	22·78	*23·14

*Mill assumes uniform conditions

Discharge.

(Continued from previous page.)

Grading Analyses.					Mechanical Values.				
Screen.	B 7.	B 8.	B 9.	B 10.	Screen.	B 7.	B 8.	B 9.	B 10.
20	0·75	0·75	0·75	0·75	20	0·11	0·11	0·11	0·11
30	4·50	5·00	5·25	5·00	30	0·77	0·85	0·89	0·85
50	15·75	15·00	15·00	15·00	50	2·99	2·85	2·85	2·85
80	24·25	24·00	24·00	23·00	80	5·10	5·04	5·04	4·93
120	14·00	14·00	14·50	14·75	120	3·22	3·22	3·34	3·39
200	14·50	14·25	13·50	14·00	200	3·62	3·56	3·38	3·50
−200	26·25	27·00	26·75	27·00	−200	7·35	7·56	7·49	7·56
Loss Correction	—	—	0·25	—	—	—		0·06	—
	100·00	100·00	100·00	100·00		23·16	23·19	23·16	23·19

Efficiency.

Capacity of mill	12·6 tons per 24 hours.
Total power consumed	6744 watts.
Power consumed (running light)	3052 „
Power consumed by mill	3692 „ = 5·0 hp.
Mechanical value of discharge...	23·18
„ „ intake	20·36
Work done per unit	2·82

Relative mechanical efficiency per hp. ... $\frac{2{\cdot}82 \times 12{\cdot}6}{5} = 7{\cdot}11$

TEST "O." (FIG. 2.)

Feed.............................. 14·4 tons per 24 hours.
Moisture .... 38%.
Pebble load .... 1200 lb.
Rev. per min.................... 41.
Length of test .... 45 minutes.

Screen.	Intake.	Discharge.
	Grading Analysis.	Grading Analysis.
20	12·0	1·0
30	21·0	6·0
50	22·0	16·5
80	19·0	23·0
120	9·5	14·0
200	8·0	14·0
–200	8·5	25·5
TOTAL	100·0	100·0

EFFICIENCY.

Capacity of mill .... 14·4 tons per 24 hours.
Total power consumed .... 7126 watts.
Power consumed (running light) 2956 „

Power consumed by mill .... 4170 „ = 5·6 hp.
Mechanical value of discharge ... 23·00
„ „ intake ...... 20·09

Work done per unit......... 2·91

Relative mechanical efficiency per hp....... $\frac{2·91 \times 14·4}{5·6} = 7·48.$

"TEST C." (FIG. 2.)

Feed	9·6 tons per 24 hours.
Moisture	38 %.
Pebble load	1200 lb.
Rev. per. min	41.
Length of test	60 minutes.

Screen.	Intake.	Discharge.
	Grading Analysis.	Grading Analysis.
20	12·0	0·5
30	20·0	3·0
50	21·5	12·0
80	18·5	22·0
120	9·5	16·0
200	9·0	16·5
–200	9·5	30·0
TOTAL	100·0	100·0

EFFICIENCY.

Capacity of mill	9·6 tons per 24 hours.		
Total power consumed	12,396 watts.		
Power consumed (running light)	8,640	,,	
Power consumed by mill	3,756	,,	= 5·0 hp.
Mechanical value of discharge	23·61		
,, ,, intake	20·25		
Work done per unit	3·36		

Relative mechanical efficiency per hp.... $\frac{3·36 \times 9·6}{5·0} = 6·45.$

TEST "R." (FIG. 2.)

Feed	23 tons per 24 hours.
Moisture	38 %.
Pebble load	1200 lb.
Rev. per min.	41.
Length of test	60 minutes.

Screen.	Intake.	Discharge.
	Grading Analysis.	Grading Analysis.
20	13·5	2·0
30	19·5	9·0
50	21·0	19·0
80	17·5	21·5
120	7·0	10·5
200	7·5	14·0
– 200	14·0	24·0
TOTAL	100·0	100·0

EFFICIENCY.

Capacity of mill	23 tons per 24 hours.	
Total power consumed	8555 watts.	
Power consumed (running light)	3639 ,,	
Power consumed by mill	4916 ,,	= 6·6 hp.
Mechanical value of discharge	23·57	
,, ,, intake	20·48	
Work done per unit	2·09	

Relative mechanical efficiency per hp.... $\frac{23 \cdot 0 \times 2 \cdot 09}{6 \cdot 6} = 7 \cdot 28.$

TEST "P." (FIG. 2.)

Feed	7·2 tons per 24 hours.
Moisture	38 %.
Pebble load	1200 lb.
Rev. per min.	41.
Length of test	65 minutes.

Screen.	Intake. Grading Analysis.	Discharge. Grading Analysis.
20	11·0	0·5
30	19·5	2·0
50	21·0	9·0
80	18·5	20·0
120	7·5	15·5
200	8·5	17·0
−200	14·0	36·0
TOTAL ...	100·0	100·0

EFFICIENCY.

Capacity of mill	7·2 tons per 24 hours.	
Total power consumed	7587 watts.	
Power consumed (running light)	2913 ,,	
Power consumed by mill	4674 ,,	= 6·3 hp.
Mechanical value of discharge...	24·34	
,, ,, intake	20·45	"
Work done per unit	3·89	

Relative mechanical efficiency per hp.... $\frac{3{\cdot}89 \times 7{\cdot}2}{6{\cdot}3} = 4{\cdot}45.$

TEST "A." (FIG. 2.)

Feed............................18·6 tons per 24 hours.
Moisture ....33 %.
Pebble load ....1200 lb.
Rev. per min ....41.
Length of test ....60 minutes.

Screen.	Intake.	Discharge.
	Grading Analysis.	Grading Analysis.
20	11·0	1·0
30	19·5	7·5
50	21·5	18·5
80	18·0	24·0
120	10·5	14·5
200	9·5	13·5
–200	10·0	21·0
TOTAL	100·0	100·0

EFFICIENCY.

Capacity of mill .... 18·6 tons per 24 hours.
Total power consumed ... . 7038 watts.
Power consumed (running light) 3074 „

Power consumed by mill .... 3964 „ = 5·3 hp.
Mechanical value of discharge ... 27·57
„ „ intake ...... 20·36

Work done per unit ...... 2·21

Relative mechanical efficiency per hp.... $\frac{2{\cdot}21 \times 18{\cdot}6}{5{\cdot}3} = 7{\cdot}76.$

SERIES II.

8. *Data and results of Moisture Tests.*—In the second series of tests the amount of moisture was varied, and the rate of feed, speed and pebble load were maintained at a constant figure.

SUMMARY OF TESTS.

Test.	Feed per 24 hours.	Pebble Load.	Moisture.	Rev. per Min.	Hp.	Work done per Unit.	Relative Mech. Efficiency per hp.
	Tons.	lb.	%.				
D ..	12·6	1200	30	41	5·7	2·99	6·91
* (E1) ...	12·6	1200	$33\frac{1}{3}$	41	5·6	2·95	6·64
(E2) ...	12·6	1200	$36\frac{2}{3}$	41	5·7	3·08	6·81
† B ...	12·6	1200	$37\frac{7}{10}$	41	5·0	2·82	7·11
* (E3) ...	12·6	1200	40·0	41	5·7	3·01	6·65
* (E4) ...	12·6	1200	$43\frac{1}{3}$	41	6·1	3·07	3·36
* (E5) ...	12·6	1200	$46\frac{2}{3}$	41	6·0	2·97	6·24
E ...	12·6	1200	50·0	41	6·2	3·05	6·16
* (F1) ...	12·6	1200	$53\frac{1}{3}$	41	6·2	3·00	6·10
* (F2) ...	12·6	1200	$56\frac{2}{3}$	41	6·1	2·92	6·01
F ...	12·6	1200	58·0	41	6·0	2·84	5·96

* Data obtained from "Transition Samples." (See p. 50.)

† Most efficient test.

CRUSHING EFFICIENCY.

Test.	Moisture.	No. of tons crushed to "-120" grade per 24 hours.	Percentage of Total Feed.
D	30	2·93	23·75
B	37·7	2·95	23·5
E	50	2·95	23·5
F	58	2·97	23·75

TESTS ON VARIATION OF MOISTURE.

In conducting these moisture tests a procedure was decided upon which the author believes to be original.

From the tests already completed on the variation of feed, it had been clearly proved, both by the power consumption and screen analyses, that the mill assumed uniform conditions after a period of about 35 minutes from the start of the test.

This fact gave rise to the following idea:—

"If the mill was run for a given time at a certain fixed moisture until the conditions had had time to become uniform, and the moisture was then suddenly raised to another fixed point without stopping the mill, but allowing it to run for the same period, would one not be justified in assuming that the samples and power readings, taken during the transition period of the mill from one state of normal conditions to the next, are representative of its product caused by the amount of moisture in it at that exact moment at which the sample was taken?"

To test this theory, samples and power readings were taken at intervals of five minutes throughout the three tests, and the results were most satisfactory.

It was found that whereas the mill took 30 minutes to adjust itself after the moisture had been changed from 30% to 50%, it took only 12 minutes to assume uniform conditions from a change of 50% up to 58%, thus indicating that the time of change was proportional to the amount of change of moisture.

With the above fact so clearly demonstrated, it was a simple matter to calculate what percentage of moisture the mill contained at the precise moment when each "Transition Sample" was taken, *e.g.*, since the first transition period was 30 minutes and five samples were taken during that time, the corresponding percentages of moisture would be $33\frac{1}{3}$ %, $36\frac{2}{3}$ %, 40 %, $43\frac{1}{3}$ % and $40\frac{2}{3}$ %.

By glancing at the "moisture efficiency" and "moisture power" curves (Fig. 3) it will be seen with what remarkable regularity the points obtained from these transition samples coincided with the curve drawn through the main points obtained for the actual tests.

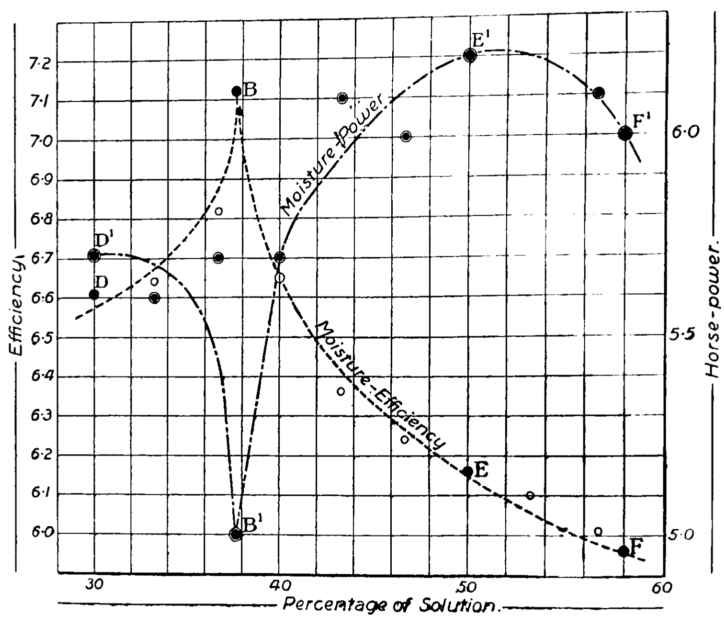


Fig. 3.

Hence the adoption of this method was more than justified, as it involved both a considerable economy of material, time and labour, and the obtaining of a number of "moisture efficiencies" which would otherwise have been impossible.

As an example of the practical utility of this method, it should be possible to obtain curves for a tube-mill, from which the efficiency and power at any percentage of moisture from say 20 % to 80 % could be obtained by simply running a continuous test of $3\frac{1}{2}$ hours, assuming that the mill takes 30 to 35 minutes to run uniformly, and changing the moisture by increases of 20 % at intervals of 50 minutes.

By examining the curves of Fig. 3 it will be seen how astonishingly the efficiency curve culminates at a point with a moisture of 37·7 %. Above and below this point the efficiency curve decreases, first sharply and then gradually. It is also a notable fact that the "moisture power" curve is practically the "efficiency" curve inverted.

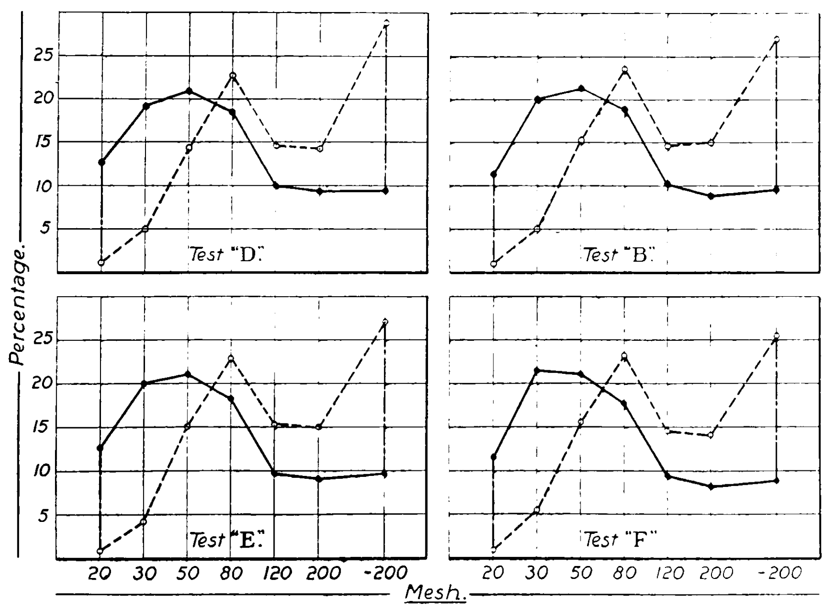


FIG. 4.

The work done per unit varies somewhat with the percentages of moisture, which range from 30 % to 58 %, but the hp. drops sharply to a minimum, then rises, first almost perpendicularly and then gradually, until after a moisture of 52 % has been passed, when it starts to descend rather sharply again.

From the symmetry of the curve it seems certain that a moisture of 37·7 % is the most efficient one for the mill under consideration, and it coincides very closely with the critical point of 38·4 % found by Mr. Walter Neal, and that of 38·5 % found by Mr. G. O. Smart. A comparison of the three results will be taken up later.

TESTS "D," "E" and "F." (FIG. 4.)

Constant feed........................	12·6 tons per 24 hours.
Constant pebble load..............	1200 lb.
Varying moisture	30 % (Test "D").
,, ,, ...	50 % (,, "E").
,, ,, ...	58 % (,, "F").
Total time to run	2½ hours.

Feed Test:—

Diam. of cone aperture	¾ in.
Weight of sand for 10 min. run	105 lb.
Calculated charge for 2½ hours	2625 lb.
Actual charge used	2657
Difference	32 lb.
Hence capacity of mill...........	12·6 tons per 24 hours.

MOISTURE TESTS.

Remarks.	Notch.	Wt. Water.	Time.	Percentage.
		lb.	min.	
Before run	1·42	250	5	30
After ,, ...	1·42	455	5	30
Before ,, ...	1·85	87·5	5	50
After ,, ...	1·85	140·4	8	50
Before ,, ...	2·10	122·0	5	58
After ,, ...	2·10	123·0	5	58

TEST "D." (FIG. 4.)

Moisture	30 %.
Feed	12·6 tons per 24 hours.
Pebble load	1200 lb.
Rev. per min	41.
Length of test	50 minutes.

Screen.	Intake. Grading Analysis.	Discharge. Grading Analysis.
20	12·5	1·0
30	19·0	5·0
50	20·5	14·5
80	18·5	22·5
120	10·5	14.5
200	9·5	14·0
−200	9·5	28·5
TOTAL	100·0	100·0

EFFICIENCY.

Capacity of mill	12·6 tons per 24 hours.	
Total power required	7260 watts.	
Power required (running light)	3007 „	
Power consumed by mill	4253 „	= 5·7 hp.
Mechanical value of discharge...	23·33	
„ „ intake	20·34	
Work done per unit	2·99	

Relative mechanical efficiency per hp.... $\frac{2·99 \times 12·6}{5·7} = 6·61.$

TEST "E." (FIG. 4.)

Moisture .... 50 %.
Feed .... 12·6 tons per 24 hours.
Pebble load..................... 1200 lb.
Length of run.................. 50 minutes.
Rev. per min.................... 41.

Screen.	Intake.	Discharge.
	Grading Analysis.	Grading Analysis.
20	12·5	0·5
30	20·0	4·5
50	21·0	15·0
80	18·5	22·5
120	9·5	15·5
200	9·0	15·0
– 200	9·5	27·0
TOTAL	100·0	100.0

EFFICIENCY.

Capacity of mill .... 12·6 tons per 24 hours.
Total power required .... 7776 watts.
Power required (running light)... 3134 "

Power consumed by mill .... 4642 " = 6·2 hp.
Mechanical value of discharge ... 23·30
" " intake ...... 20·27

Work done per unit ...... 3·03

Relative mechanical efficiency per hp.... $\frac{3{\cdot}03 \times 12{\cdot}6}{6{\cdot}2} = 6{\cdot}16$.

TEST "F."

Moisture	58 %.
Feed	12·6 tons per 24 hours.
Pebble load	1200 lb.
Length of run..................	50 minutes.
Rev. per min.	41.

Screen.	Intake. Grading Analysis.	Discharge. Grading Analysis.
20	11·5	1·0
30	21·5	5·5
50	21·5	15·5
80	18·5	23·5
120	9·5	14·5
200	8·5	14·5
–200	9·0	25·5
TOTAL	100·0	100·0

EFFICIENCY.

Capacity of mill	12·6 tons per 24 hours.		
Total power consumed	7779 watts.		
Total power required (running light)	3260	,,	
Power consumed by mill	4519	,,	= 6·0 hp.
Mechanical value of discharge	23·07		
,, ,, intake...........	20·23		
Work done per unit	2·84		

Relative mechanical efficiency per hp......... $\frac{2{\cdot}84 \times 12{\cdot}6}{6{\cdot}0} = 5{\cdot}96.$

SERIES III.

9. *Data and results of Pebble Load Tests.*—In the third series of tests the amount of the pebble load was varied, and the degree of moisture, rate of feed and speed were maintained at a constant figure.

Summary of Tests.

Test.	Feed per 24 hours.	Pebble Load.	Moisture.	Rev. per Min.	Hp.	Work done per Unit.	Relative Mech. Efficiency per hp.
	Tons.	lb.	%				
B	12·6	1200 ($\frac{1}{2}$)	38	41	5·1	2·82	7·02
*G	12·6	900 ($\frac{3}{8}$)	38	41	1·9	2·75	7·07
H	12·6	1500 ($\frac{5}{8}$)	38	41	6·9	3·31	6·04

* Most efficient.

Crushing Efficiency.

Test.	Pebble Load.	No. of tons crushed to "–120" grade per 24 hours.	Percentage of Total Feed.
B	1200 lb.	2·78	22
G	900 ,,	2·65	21
H	1500 ,,	3·40	27

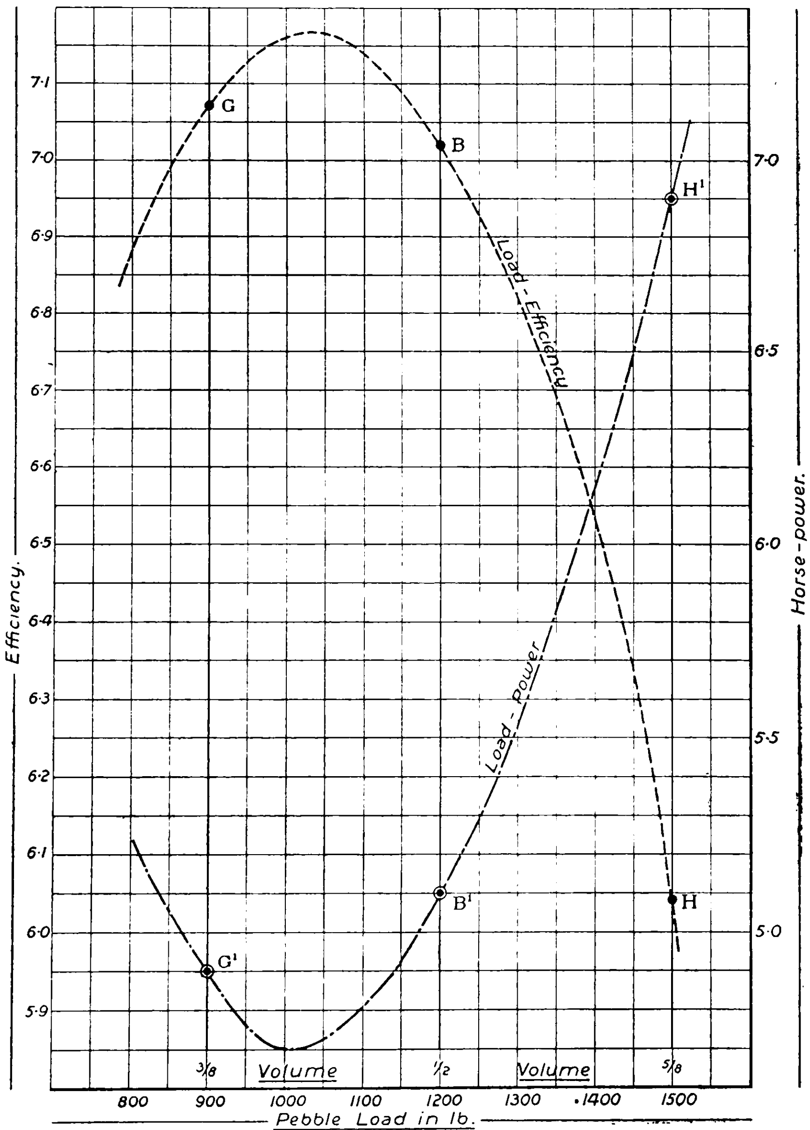

Efficiency.
7·1
7·0
6·9
6·8
6·7
6·6
6·5
6·4
6·3
6·2
6·1
6·0
5·9
G
B
H¹
H
G¹
B¹
Load - Efficiency
Load - Power
Horse-power.
7·0
6·5
6·0
5·5
5·0
3/8
Volume
1/2
Volume
5/8
800
900
1000
1100
1200
1300
1400
1500
Pebble Load in lb.

FIG. 5.

In this series three tests were run, the volume occupied by the pebbles being respectively $\frac{3}{8}$, $\frac{1}{2}$ and $\frac{5}{8}$ of the total volume of the mill.

Contrary to expectations it was found that the efficiency obtained with pebble volumes of $\frac{3}{8}$ and $\frac{1}{2}$ of the total volume of the mill was very nearly the same, and with an increase of pebbles the efficiency dropped rapidly. The most efficient load used was the smallest

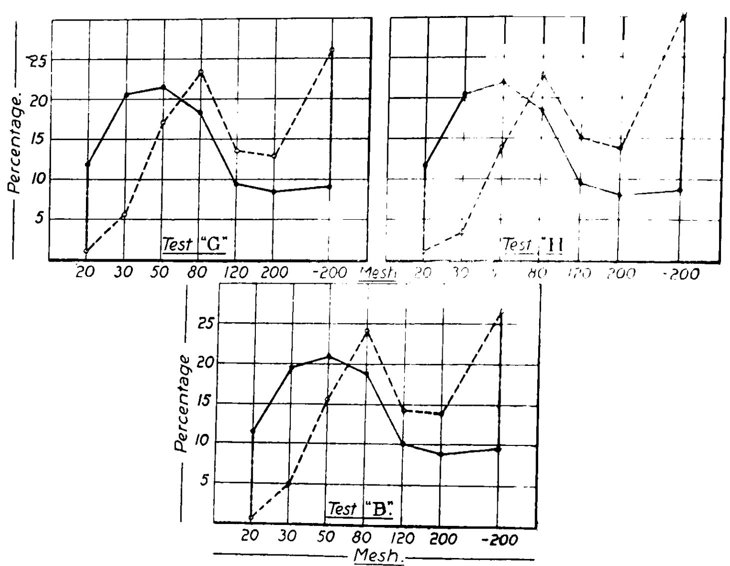


Fig. 6.

one; the conclusion obtained from the "efficiency" curve was that the most efficient pebble load would be about 1050 lb. = $\frac{7}{16}$ of the mill volume (Fig. 5).

Considering the crushing efficiency only of the different loads, the heaviest load gives by far the highest efficiency, which would seem to coincide with modern practice where 0·6 of the mill volume is generally occupied by the pebbles.

Test "G." (Fig. 6.)

Pebble load	900 lb. = ⅜ volume.
Feed	12·6 tons per 24 hours.
Moisture	37·7 %.
Rev. per min.	41.
Time of test	60 minutes.

Screen.	Intake. Grading Analysis.	Discharge. Grading Analysis.
20	12·0	1·0
30	21·0	6·0
50	21·5	17·0
80	18·5	23·5
120	9·5	13·5
200	8·5	13·0
–200	9·0	26·0
Total	100·0	100·0

Efficiency.

Capacity of mill	12·6 tons per 24 hours.	
Total power required	6612 watts.	
Power required (running light)	2950 ,,	
Power consumed by mill	3662 ,,	= 4·9 hp.
Mechanical value of discharge.........	23·01	
,, ,, intake	20·26	
Work done per unit	2·75	

Relative mechanical efficiency per hp............ $\frac{2\cdot75 \times 12\cdot6}{4\cdot9} = 7\cdot07.$

TEST "H." (Fig. 6.)

Pebble load .... 1500 lb. = $\frac{5}{8}$ volume.
Feed .... 12·6 tons per 24 hours.
Moisture .... 37·7 %.
Rev. per min. .... 41.
Time of test .... 50 minutes.

Screen.	Intake.	Discharge.
	Grading Analysis.	Grading Analysis.
20	12·0	1·0
30	20·0	3·0
50	22·0	14·0
80	19·0	22·5
120	10·0	15.0
200	8·0	14·0
–200	9·0	30·5
TOTAL.........	100·0	100·0

EFFICIENCY.

Capacity of mill.............................. 12·6 tons per 24 hours.
Total power consumed .... 7910 watts.
Power consumed (running light)...... 2733 ,,

Power consumed by mill .... 5177 ,, = 6·9 hp.
Mechanical value of discharge......... 23·49
,, ,, intake............ 20·18

Work done per unit......... 3·31

Relative mechanical efficiency per hp......... $\frac{3{\cdot}31 \times 12{\cdot}6}{6{\cdot}9} = 6{\cdot}04.$

SERIES IV.

10.—*Data and results of Speed Tests.*—In the fourth series of tests, the speed was varied, and the degree of moisture, rate of feed and amount of pebble load were maintained at a constant figure.

Summary of Tests.

Test.	Feed per 24 hours (Tons).	Pebble Load.	Moisture.	Rev. per min.	Hp.	Work done per Unit.	Rel. Mech. Eff. per Hp.
T ...	7·2	1200	38 %	33	6·8	4·19	4·43
*Q ...	7·2	1200	38 %	37	5·1	4·17	5·89
P ...	7·2	1200	38 %	41	6·3	3·89	4·45
S ...	7·2	1200	38 %	46	7·5	4·03	3·87

Crushing Efficiency.

Test.	Rev. per min.	No. of tons crushed to "–120" grade per 24 hours.	Percentage of total feed.	Peripheral speed per min.
T	33	2·45	34	297 ft.
*Q	37	2·59	35	333 ,,
P	41	2·27	31·5	369 ,,
S	46	2·48	34·5	414 ,,

* Most efficient.

In these tests the number of revolutions of the tube-mill was varied by altering the position of the brushes on the commutator of the motor, this increasing or decreasing its speed.

The result obtained is interesting, as it is plainly proved that 37 rev. per min. is the most efficient speed for the laboratory tube-mill.

A marked coincidence is revealed by the fact that the power required to drive the mill at 33 rev. per min. is just 0·5 hp. more than that required to drive it at 41 rev. per min. whilst the "efficiency" in each case is practically the same. This indicated

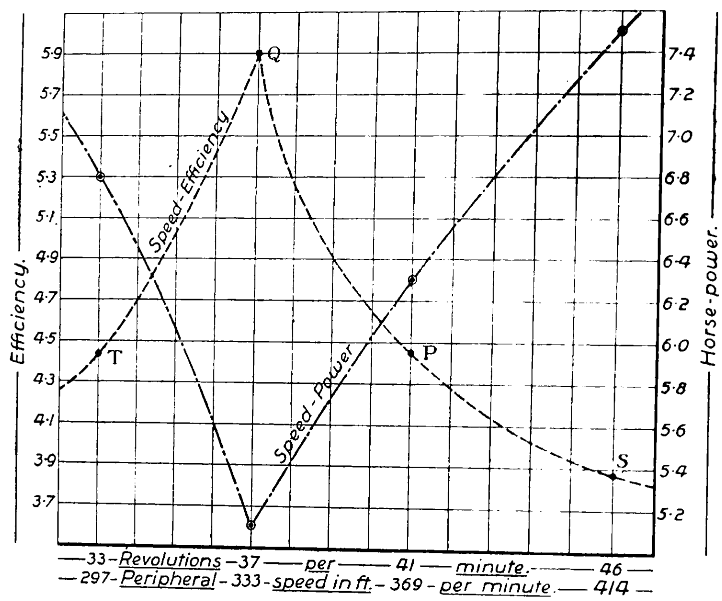


FIG. 7.

that a speed between these two would be the most efficient. How well this was actually borne out is shown by both the efficiency and power curves (Fig. 7).

Whilst the power decreased by about 22%, the efficiency is increased by 32%, thus the grinding itself must be more efficient, which is again proved by the crushing diagrams (Fig. 8). On running a further test at a speed of 46 rev. per min. it was found that the power had perceptibly increased, thus bringing the efficiency lower still. As regards the crushing done at this speed, it is slightly better than at 41 rev. per min., but not enough to counterbalance the extra quantity of power needed.

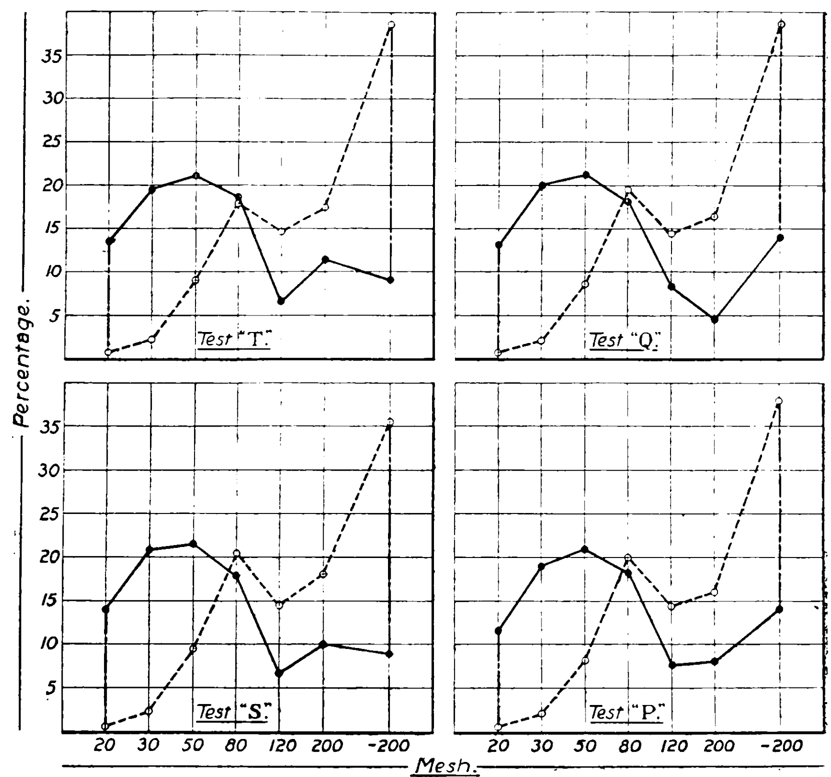

Percentage.
35
30
25
20
15
10
5
Test "T."
Test "Q."
Test "S."
Test "P."
20 30 50 80 120 200 -200
Mesh.

FIG. 8.

TEST "Q." (FIG. 8.)

Rev. per min.	37.
Feed	7·2 tons per 24 hours.
Moisture	38 %.
Pebble load	1200 lb.
Length of test	45 minutes.

Screen.	Intake. Grading Analysis.	Discharge. Grading Analysis.
20	13·0	0·5
30	20·0	2·0
50	21·5	8·5
80	18·5	19·5
120	8·5	14·5
200	4·0	16·5
−200	14·5	38·5
TOTAL ...	100·0	100·0

EFFICIENCY.

Capacity of mill .... 7·2 tons per 24 hours.
Total power consumed .... 6969 watts.
Power consumed (running light) 3178 „

Power consumed by mill .... 3791 „ = 5·1 hp.
Mechanical value of discharge ... 24·38
„ „ inlet .... 20·21

Work done per unit ...... 4·17

Relative mechanical efficiency per hp.... $\frac{4 \cdot 17 \times 7 \cdot 2}{5 \cdot 1} = 5 \cdot 89.$

Test "S." (Fig. 8.)

Rev. per min. .... 46.
Feed .... 7·2 tons per 24 hours.
Moisture .... 38 %.
Pebble load .... 1200 lb.
Length of test.................. 60 minutes.

Screen.	Intake. Grading Analysis.	Discharge. Grading Analysis.
20	14·0	0·5
30	20·5	2·5
50	21·5	9·5
80	18·0	20·5
120	6·5	14·5
200	10·0	16·5
–200	9·5	36·0
Total ...	100·0	100·0

Efficiency.

Capacity of mill .... 7·2 tons per 24 hours.
Total power consumed .... 9451 watts.
Power consumed (running light) 3834 „

Power consumed by mill .... 5617 „ = 7·5 hp.
Mechanical value of discharge ... 24·12
„ „ intake ...... 20·09

Work done per unit .... 4·03

Relative mechanical efficiency per hp........ $\frac{4·03 \times 7·2}{7·5} = 3·87$.

TEST "T." (Fig. 8.)

Rev. per min.	33.
Feed	7·2 tons per 24 hours.
Moisture	38 %.
Pebble load	1200 lb.
Length of test	60 minutes.

Screen.	Intake.	Discharge.
	Grading Analysis.	Grading Analysis.
20	13·5	0·5
30	19·5	2·0
50	21·0	9.0
80	18·5	18·0
120	6·5	15·0
200	11·5	17·0
–200	9·5	38·5
Total ...	100·0	100·0

EFFICIENCY.

Capacity of mill	7·2 tons per 24 hours.	
Total power consumed	9081 watts.	
" " " (running light)	4034 "	
Power consumed by mill	5047 "	= 6·8 hp.
Mechanical value of discharge	24·39	
" " intake	20·20	
Work done per unit	4·19	

Relative mechanical efficiency per hp. .... $\frac{7{\cdot}2 \times 4{\cdot}19}{6.8} = 4{\cdot}43.$

GENERAL SUMMARY OF TESTS.

Remarks.	Test.	Pebble load.	Pebble vol.	Rev. per min.	Peripheral speed min.	Moisture. %.	Feed. Tons per 24 hrs.	Hp.	Work done per unit.	Net output "–120 grade" (tons 24 hrs.)	Rel. mech. eff. per hp.
Feed tests	P	lb. 1200	0·5	41	369 ft.	38·0	7·2	6·3	3·89	2·27	4·45
	C	1200	0·5	41	369 ,,	38·0	9·6	5·0	3·36	2·34	6·45
	B	1200	0·5	41	369 ,,	38·0	12·6	5·1	2·82	2·95	7·02
	O	1200	0·5	41	369 ,,	38·0	14·4	5·6	2·91	3·31	7·48
	*A	1200	0·5	41	369 ,,	38·0	18·6	5·8	2·58	3·96	8·29
	R	1200	0·5	41	369 ,,	38·0	23·0	6·6	2·09	3·79	7·28
Moisture tests	D	1200	0·5	41	369 ft.	30·0	12·6	5·7	2·99	2·93	6·61
	*B	1200	0·5	41	369 ,,	37·7	12·6	5·0	2·82	2·95	7·11
	E	1200	0·5	41	369 ,,	50·0	12·6	6·2	3·05	2·95	6·16
	F	1200	0·5	41	369 ,,	58·0	12·6	6·0	2·84	2·97	5·96
Pebble load tests	*G	900	0·37	41	369 ft.	38·0	12·6	4·9	2·75	2·65	7·07
	B	1200	0·50	41	369 ,,	38·0	12·6	5·1	2·82	2·78	7·02
	H	1500	0·63	41	369 ,,	38·0	12·6	6·9	3·31	3·40	6·04
Speed tests	T	1200	0·5	33	297 ft.	38·0	7·2	6·8	4·19	2·45	4·43
	*Q	1200	0·5	37	333 ,,	38·0	7·2	5·1	4·17	2·59	5·89
	P	1200	0·5	41	369 ,,	38·0	7·2	6·3	3·89	2·27	4·45
	S	1200	0·5	46	414 ,,	38·0	7·2	7·5	4·03	2·48	3·87

* Most efficient test of series.

Feed Tests.

From the results obtained it was found that a feed of 18 tons per 24 hours is the most efficient one for the laboratory mill, any larger feed apparently causing the crushing efficiency, as well as the relative mechanical efficiency, to decrease.

This is a most interesting point, as a critical feed is indicated, above which it seems probable that the fine grinding properties of the mill decrease in proportion approximately to the increase of feed.

Fig. 2 (Series I), p. 16, shows that with a feed of 23 tons per 24 hours, only *3·79 tons* of "– 120 grade" per 24 hours were obtained, whereas the same fine grade output would be obtained by crushing only 18 tons through a similar period; this fact shows that the "critical feed" has been passed between these two amounts.

The theory of a "critical feed" may have an important bearing on modern practice, as it would seem that more efficient working, with a greater output of "slimes," would be obtained if a smaller feed were used.

In South Africa the tendency at present is to increase the feed in the 5½ ft. by 22 ft. mills, and although they are now feeding at the rate of 400 tons per 24 hours, the belief is held that even heavier feeds would result in increased grinding.

The above results show the danger of carrying this too far.

Using these figures as a basis and roughly calculating the feed for the laboratory mill, it appears that a feed of about 25 tons per 24 hours should result in more grinding than with a smaller feed, whereas the experimental results obtained in these tests indicate that this feed is less efficient than a smaller feed and that the most efficient feed for this mill approximates 18 tons in 24 hours.

Admitting the discrepancy of comparing two mills differing so radically as to size, it is at least of interest to note that, if any analogy can be drawn, the indications are that the South African mills are overfed and that a feed of about 300 tons instead of 400 tons per 24 hours might result in both increased grinding and efficiency.

Moisture Tests.

The outstanding feature of these tests is the great efficiency of 37·7 % moisture over all others. This fact coincides remarkably well with tests carried on in other parts of the world.

In those conducted by Walter Neal,* his results seem to prove the

* *Min. & Sci. Press*, April 2nd, 1910.

fact that the ideal dilution is in the neighbourhood of 39 % moisture, although he inclines to the belief that this "critical point" will vary with the nature and size of the mill. The results of the author's tests tend to disprove this belief.

Sherrod, experimenting with tube-mills at the Guerrero Mill, Real del Monte, finds that the "grinding efficiency" increases with the percentage of solids in feed up to about 55 or 60 %, *i.e.*, 45 40 % moisture.

G. O. Smart* claims that in the tests carried out on the Rand he has found that 38·5% moisture is the most efficient, whilst H. W. Fox† has discovered that, taking the power consumed in conjunction with the "fine grinding," the most efficient moisture would be 39·6 %.

It will be noticed that all these critical points are from 1 % to 2 % higher than the one found by the author, but this seems to be explained by the fact that the sands used, being 18 mesh, were of a finer nature than those commonly used in practice.

Regarding this critical moisture point, it has been suggested by Professor J. W. Bell‡ that it depends upon the percentage of voids in sand, and that in all probability when the percentage of moisture is numerically equal to the percentage of voids in the sand inside the mill, the moisture is "critical."

This theory is of interest in that it indicates that sand-feeds with higher or lower percentages of voids may have higher or lower critical moistures.

Comparison of Moisture Curves.—In the appended set of curves, Fig. 9 is the "moisture efficiency" curve of Neal, Fig. 10 that of Fox, and Fig. 11 that of the author. It will be noticed that in all three a peak occurs at some point between 37 % and 40 % moisture.

It is somewhat difficult to draw comparisons between the curves, for in Fig. 11 the power plays an important part in the calculation of the efficiency, whereas in the first two it is neglected.

The power curves in Figs. 10 and 11 both have the peculiarity of an inverted peak at the critical point, followed by a gradual rise until just past 50 % moisture; from this point in Fig. 10 it follows a straight line, while in Fig. 11 it gradually drops.

The second interesting feature of these tests was the use of the "transition samples" for obtaining intermediate moisture efficiency therefrom. This appears to be a practicable method of obtaining a number of points of "efficiency" and "power" at various inter-

* *Jl. of Chem., Met. & Min. Soc. of S.A.*, May 10th, 1910.

† *Mines and Minerals*, June, 1908.

‡ *Mining Magazine*, April, 1911.

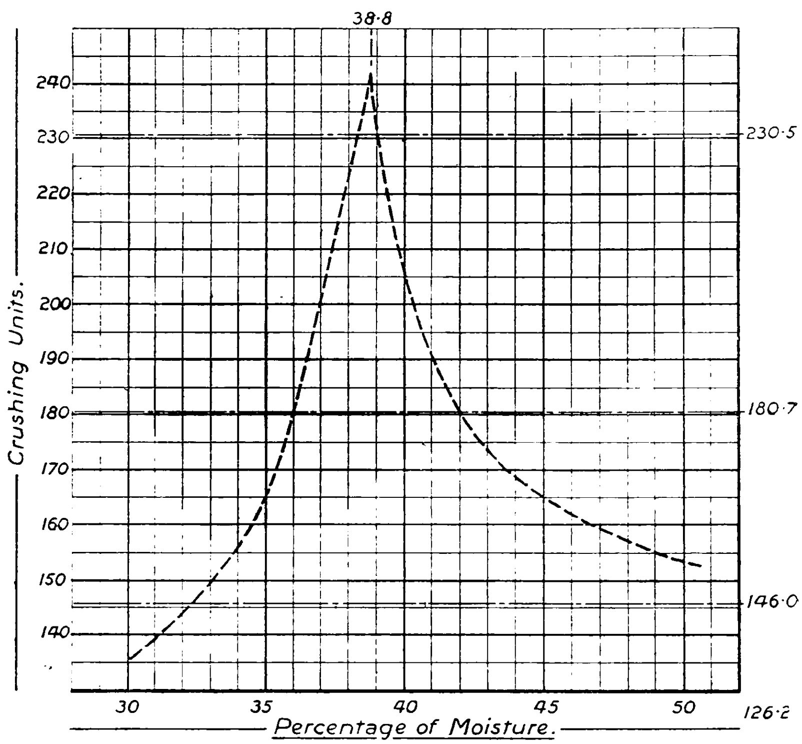


FIG. 9.—"Neal" Tests.

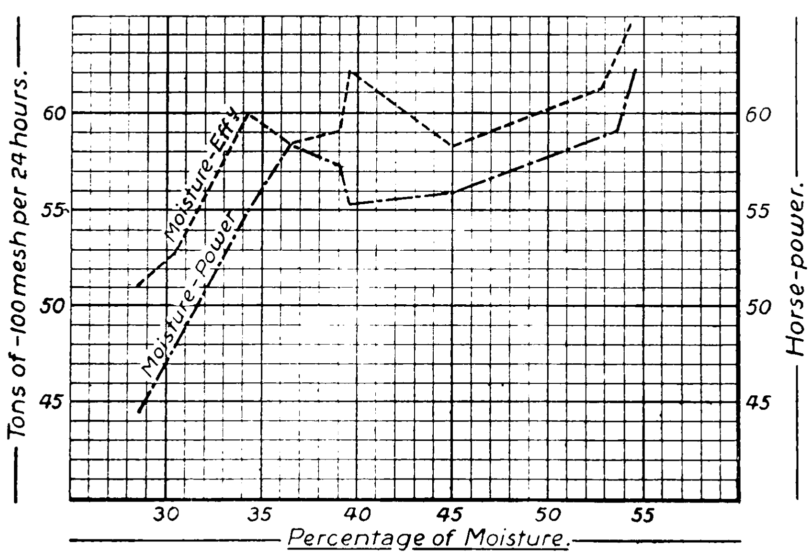


FIG. 10.—"Fox" Tests.

mediate quantities of moisture, by simply running a long continuous test and at equal periods charging the moisture without stopping the mill. In the compilation of data and curves this should be of great service both as a check on the work and for effecting a substantial economy in time and labour.

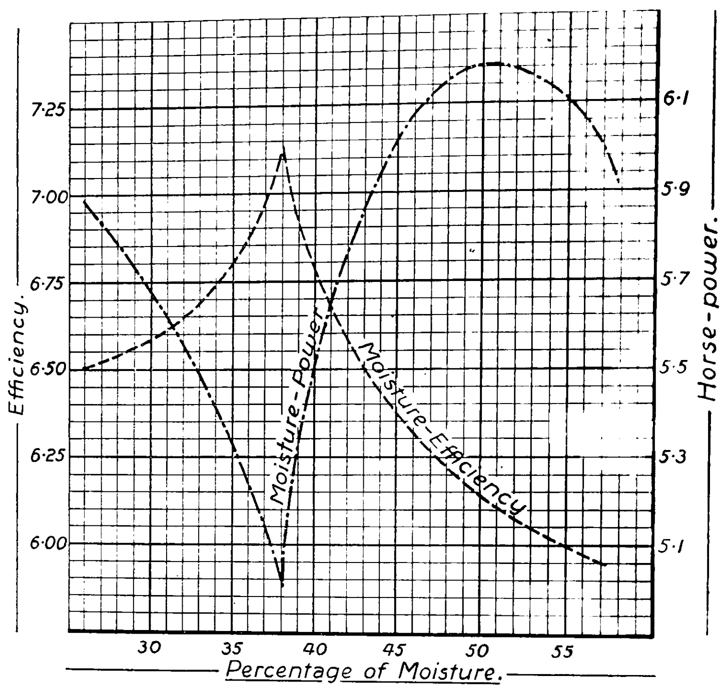


FIG. 11.—"Ball" Tests.

PEBBLE LOAD TESTS.

The result from these tests indicated that the most efficient pebble load is about $\frac{7}{16}$ of volume of mill (or for this mill 1030 lb.), whereas, disregarding power, the most effectual "crushing load" is about 0·6 of the volume which corresponds to present Rand practice.

Whether it would pay to sacrifice power and gain fine grinding, or *vice versa*, would, of course, depend upon the conditions of the plant.

SPEED TESTS.

These tests were most interesting, as they proved rather conclusively that 37 rev. per min., at a peripheral speed of 333 ft. per minute, was the most efficient, both in relative mechanical efficiency and grinding efficiency, thus demonstrating that at that speed the grinding was decidedly better, and the power required less.

It was seen that if this speed of 37 rev. per min. is exceeded or decreased the crushing effect of the pebbles is much reduced, while the power necessary to drive the mill is increased.

In connection with this efficient speed, it is interesting to compare it with that obtained from various formulæ.

Davidson gives as the best practical speed $N = \frac{300}{\sqrt{D}}$ in in., whilst White derives a formula $N = \frac{34 \cdot 22}{\sqrt{D}}$ in metres. (N = Speed, D = diam. of mill). Richards gives 38 rev. per min. as the best speed.

The results are set forth in the following table:—

Davidson.	White.	Richards.	By experiment.
34	39	38	37

Thus the result obtained from actual experiment corresponds very closely to the mean of these results.

GENERAL CONCLUSIONS.

In connection with the curves obtained from the different tests, it is the author's belief that there is a possibility of deducing from them the probable results that would be derived by running the mill under different conditions.

An example of this was shown in the feed tests, where the probable data for Test "A" was deduced from the curves of Test "B" (Fig. 2. p. 16).

The conclusion from this theory appears rather startling, for it seems that if one complete set of tests was run with a constant feed, the other factors being varied and the respective curves obtained, one would be able to deduce from them all the necessary information regarding any feed, provided that one test at that particular feed had been previously carried out.

As a case in point it was desired to know what the relative "mechanical efficiency" for a feed of 7·2 tons per 24 hours would be, with a moisture of 35%, speed of 37 rev. per min. and pebble volume 0·5, a test with 38 % moisture having already been run on this feed. The "moisture efficiency" curve for Test "B" (Fig. 2) was used, and the following data extracted:—

Moisture.	Feed.	Efficiency.	Difference.
38 %	12·6	7·02	0·27
38 %	7·2	4·45	
35 %	12·6	6·75	
35 %	7·2	x	

$$\text{Hence } \frac{0{\cdot}27}{1} \times \frac{4{\cdot}45}{7{\cdot}02} = 0{\cdot}18$$

$$\therefore = 4{\cdot}45 - 0.18 = 4.27.$$

By actual experiment (see Test "U" in the Appendix) the "efficiency" was found to be 4·32, a difference of 1·1 % between the theoretical and the actual result.

Transition Samples.

The calculation of intermediate points of efficiency by the method of the transition samples and power readings is of great interest (p. 28), as the efficiency and power required can be found for any intermediate point of moisture, feed, etc., between the limits of any two tests.

Period required by mill for uniform conditions.

This period was found with great accuracy by means of nine tests, the time required being checked by both power readings and screen analyses.

The more important features disclosed in this investigation may be summed up as follows:—

(1) The determination of a rate of feed, which if increased or decreased caused the efficiency of the mill to diminish in a marked manner, and consequently may be defined as a critical feed rate.

(2) The determination of a well-defined critical percentage of moisture in the feed.

(3) The determination of a critical speed for the laboratory mill (34 in. in diam.).

(4) The determination of a critical pebble load for this mill.

(5) The determination of the length of time required by the mill to assume a uniform condition following a change in adjustment. This is defined as the "transition period" of the mill.

(6) The substantial corroboration of the author's hypothesis that samples and power observations taken at intervals during the transition period may be used to determine the efficiency of the mill for the calculated conditions at the times the samples were

taken. These samples were called "transition samples" in contradistinction to "normal" samples taken after the mill has assumed a uniform condition.

(7) A method by which the data and curves obtained in one series of tests may be transposed and applied, as far as possible, for the purpose of securing further light on the phenomena disclosed by a second series.

From the foregoing results the writer was led to speculate on the probable result of a test which would combine the four critical adjustments determined in the tests already carried out.

These tests indicated that the laboratory mill worked most efficiently under the following conditions:—

(*a*)	Critical feed	18 tons per 24 hours.
(*b*)	" moisture....................	37·7 %.
(*c*)	" pebble load	1030 lb.
(*d*)	" speed	37 rev. per min.

Although the time remaining was very short, a successful effort was made and a test with the above critical factors was carried out giving results which surpassed expectations.

The relative mechanical efficiency disclosed by this test was found to be 8·82, a result which corroborates the previous work in a very striking manner when it is considered that this figure represents a fourteen per cent. (14 %) increase in efficiency above the highest efficiency found in any of the previous tests. (For details of this test see Test "V" in Appendix.)

In conclusion, it is the author's pleasant duty to acknowledge his indebtedness to the Mining Department of McGill University, and in particular to Dr. J. Bonsall Porter, the Director, and Mr. J. W. Bell, Assistant Professor of Mining, whose foresight and advice proved of material assistance throughout the investigations. His thanks are also due to Messrs. G. S. Eldridge and D. F. S. Wunsch and the Laboratory Staff, for their greatly appreciated practical help during the progress of the work.

APPENDIX.

Test "U."

Moisture .... 35%.
Feed .... 7·2 tons per 24 hours.
Pebble load..................... 1200 lb.
Rev. per min. .... 41.
Length of test.................. 50 minutes.

Grading Analyses.

Screen.	Intake.	Discharge.	
	U.	U1 and U2.	U3 and U4.
20	16·00	0·25	0·25
30	21·50	2·00	2·00
50	21·00	8·00	8·50
80	16·00	16·50	16·75
120	8·75	14·75	14·00
200	6·50	17·25	17·50
–200	10·25	40·75	41·00
Loss	—	0·50	—
Total ...	100·00	100·00	100·00

MECHANICAL VALUES.

Screen.	Mechanical Value of Mean Grade.	Intake.	Discharge.	
		U.	U1 and U2.	U3 and U4.
20	15	2·40	0·04	0·04
30	17	3·66	0·34	0·34
50	19	3·99	1·52	1·61
80	21	3·36	3·47	3·52
120	23	2·02	3·39	3·22
200	25	1·62	4·32	4·38
–200	28	2·87	11·41	11·48
Loss correction	—	—	0·12	—
Mechanical value of Sample		19·92	24·61	24·59

EFFICIENCY.

Capacity of mill .... 7·2 tons per 24 hours.
Total power consumed .... 8750 watts.
Power consumed (running light) 2960 „

5790 „ = 7·8 hp.

Mechanical value of discharge ...... 24·60
„ „ intake .... 19·92

Work done per unit ...... 4·68

Relative mechanical efficiency per hp....... $\frac{4.68 \times 7{\cdot}2}{7{\cdot}8} = 4{\cdot}32$

Efficiency computed from moisture curve ....4·27.

TEST "V."

Mill running under its most efficient conditions.

Feed............... 18 tons per 24 hours.
Moisture .... 37·7 %.
Speed .... 37 rev. per min.
Pebble Load ... 1030 lb.

Screen.	Mechanical Value of Mean Grade.	Intake.		Discharge.	
		Grading Analysis.	Mechanical Value of Intake.	Grading Analysis.	Mechanical Value of Intake.
Mech.	E.U.	%	E.U.	%	E.U.
20	15	14·25	2·14	1·75	0·27
30	17	22·50	3·82	9·00	1·53
50	19	23·75	4·51	22·50	4·27
80	21	18·50	3·89	24·75	5·19
120	23	9·00	2·07	13·50	3·11
200	25	6·50	1·62	10·25	2·56
–200	28	5·50	1·54	18·25	5·11
Loss Correction	—	—	—	—	—
Mech. Value	—	100·00	19·59	100·00	22·04

EFFICIENCY.

Capacity of mill .... 18 tons per 24 hours.
Total power consumed............ 6483 watts.
Power consumed (running light) 2772 ,,

Power consumed by mill............ 3701 ,, = 5·0 hp.
Mechanical value of discharge... 22·04
,, ,, intake ...... 19·59

Work done per unit .... 2·45

Relative mechanical efficiency per hp.... $\frac{2{\cdot}45 \times 18}{5{\cdot}0} = 8{\cdot}82$.

SUMMARY OF POWER TESTS ON MILL.

Load.	Horse Power.	Starting Torque. Hp.	Vol. of Mill.
Running Light	1·3	—	—
lb. 900	4·4	11·3	0·375
1200	4·9	15·2	0·500
1500	5·3	16·6	0.625

By comparison of the above summary with Figs. 12 and 13, it will be seen how uniformly the power increases with increase of pebbles.

Figs. 14 and 15 are those obtained by the calibration of the cone orifices and water cock.

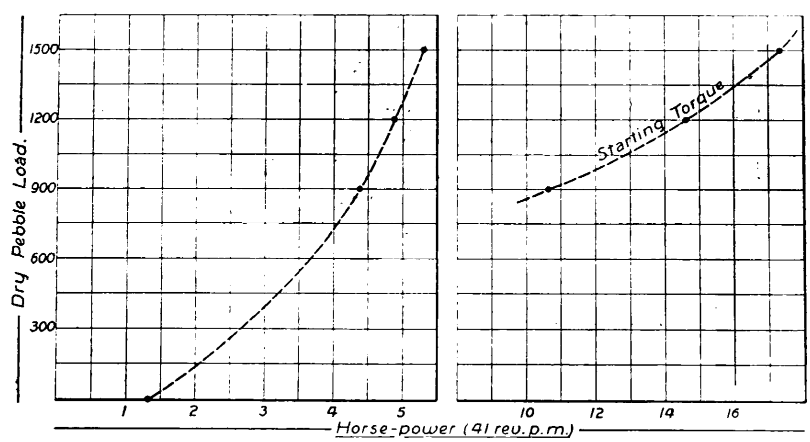


FIG. 12. FIG. 13.

Fig. 16 is interesting as it shows the growth of power required by the mill as feed is introduced, the power finally being less with full feed than with pebble load only. The lubricating action of the pulp on the pebbles is thus clearly shown.

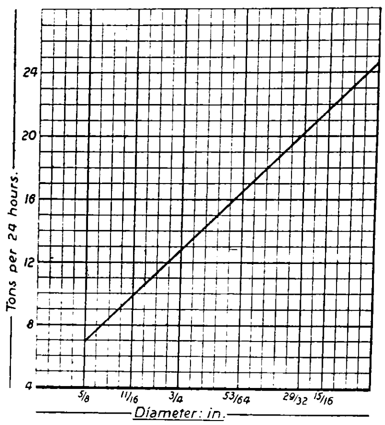


FIG. 14.

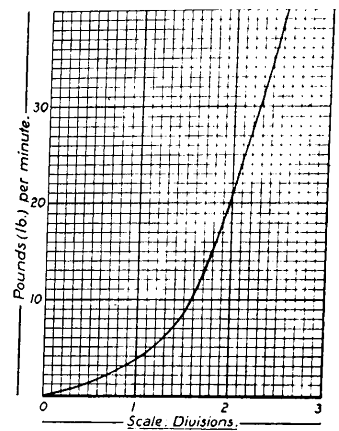


FIG. 15.

A microscopic examination of the "nepheline syenite" resulted as follows:—

Orthoclase........	Intergrown in a little "plagioclase." Much altered in parts to sericite and kaolin.
Elæolite	Trace.
Hornblende	Deep green.
Garnet	Very irregular. Large brown grains.
Sphene	Pale yellow—abundant in large asicular crystals.
Zirion	A few very small grains.
Nosean	Badly altered in calcite.
Apatite	A few grains.
Magnetite	Trace.
Pyrites	A few grains.

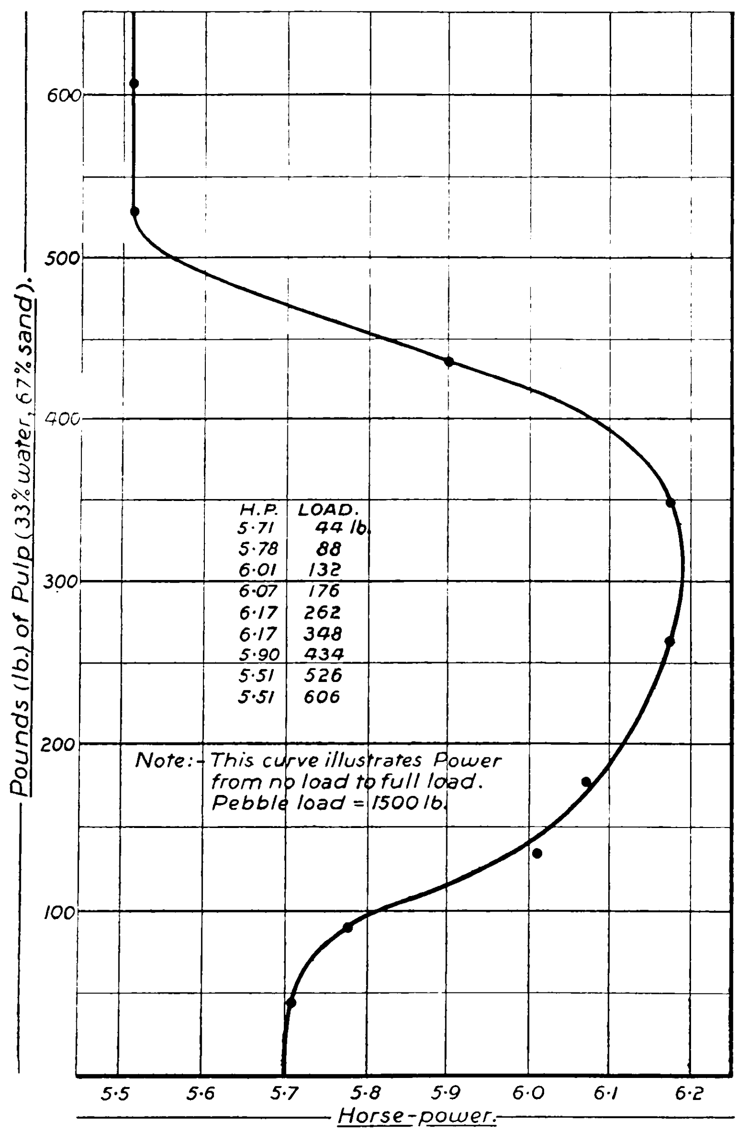

600
500
400
300
200
100
Pounds (lb.) of Pulp (33% water, 67% sand).
H.P. LOAD.
5·71 44 lb.
5·78 88
6·01 132
6·07 176
6·17 262
6·17 348
5·90 434
5·51 526
5·51 606
Note:- This curve illustrates Power from no load to full load. Pebble load = 1500 lb.
5·5
5·6
5·7
5·8
5·9
6·0
6·1
6·2
Horse-power.

Fig. 16.

BIBLIOGRAPHY.

"Ore Dressing," Richards.
"The Dressing of Minerals," H. Louis.
Trans. A.I.M.E., vols. xxxvi, xxxvii, xxxviii.
Jl. of Chem., Met. & Min. Soc. of S.A., vols. v—x.
Electric Met. Industry, vol. v.
En. & Min. Jl., vols. lxvii, lxxix.
Trans. I.M.M., vols. xiv, xvi—xx.
Mining Magazine, vol. xi.
Mining Journal, vol. lxxx.
Mines & Minerals, vols. xxx, xxvi, xxviii.
Mining Report, vols. l, lii.
Min. & Sci. Press, vols. xcl, xcii, xciii.
Mining World, vol. xxvii.
N.Z. Min. Review, vols. xii, xiii.
S.A. Min. Jl., 1910–11.

*** *Extra Copies of this paper may be obtained, at a nominal charge, at the Offices of the Institution, Salisbury House, London, E.C.*

CROWTHER & GOODMAN, Printers, 124, Fenchurch Street, London, E.C.

AN INVESTIGATION ON THE EFFICIENCY OF THE TUBE MILL.

Comprising a report on a series of original experiments.
and a revision of Ball's Paper on the "Economics of Tube Milling"

being

The second of two Theses submitted to

The Graduate School

for

Master of Science Degree

by

George E. Murray B.Sc.

McGill University.

April 15-1912.

PART 1.

1. Introduction.

2. Scope of Investigation.

3. Description of Tube Mill and Accessory Apparatus

4. Method of Carrying out the Tests.

5. Screen Analyses, Screening machine etc.

6. Mechanical Values of Grades.

PART 11.

Tabulation and Discussion of Results.

Series 1. Feed Tests.

11. Moisture Tests.

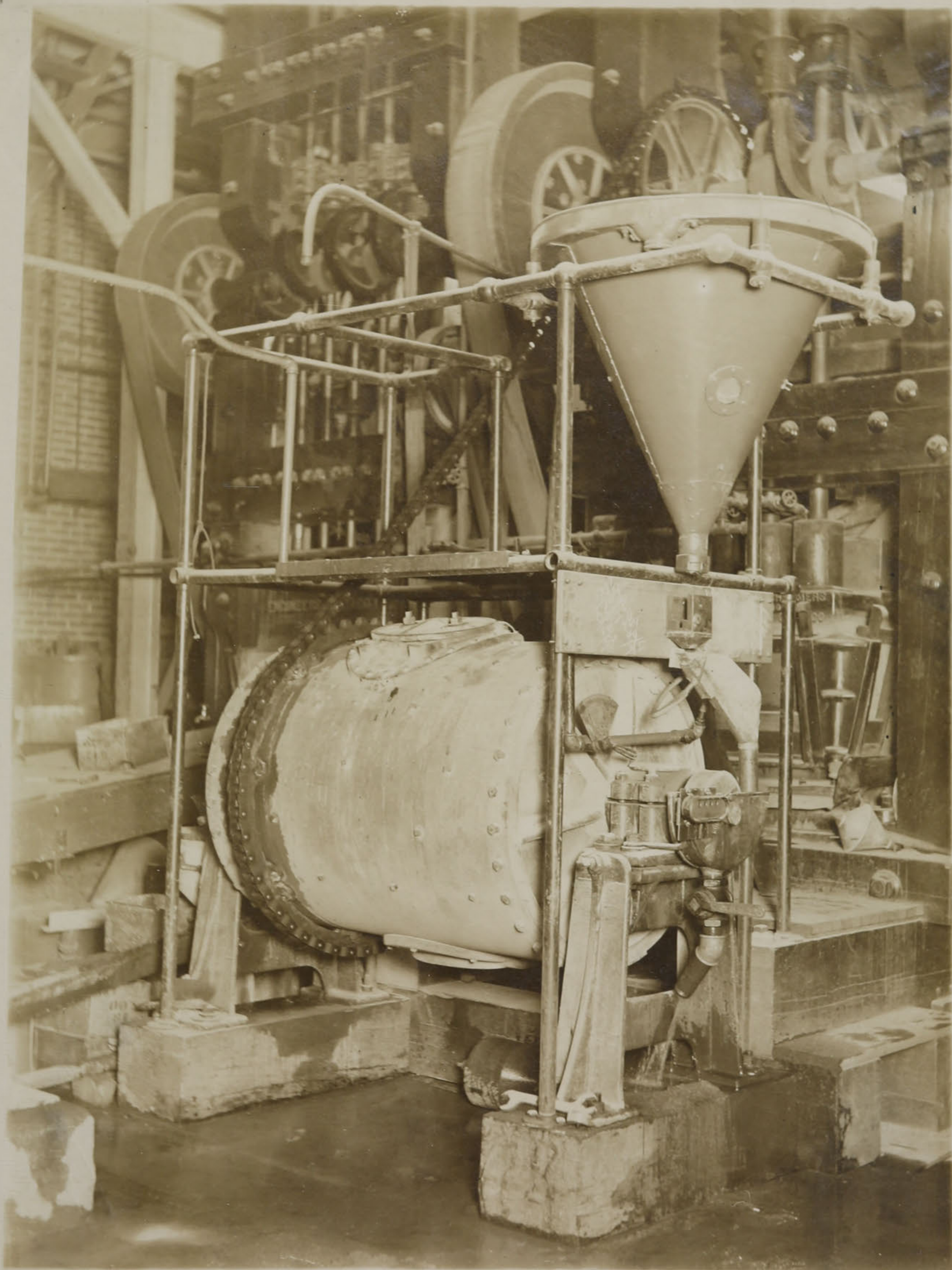
111. Speed "

1V. Size "

General Conclusions.

PART 111.

~~Delaid~~ Detailed Results including screen analyses etc.



PHOTOGRAPH SHOWING LABORATORY
TUBE - MILL.

Introduction.

The investigation on tube milling, the results of which are embodied in this paper, is a continuation of the work done by Mr. H. Standish Ball at McGill University in 1911. Mr. Ball's thesis was presented for the Master of Science degree at McGill, and the author of this paper will not deal with the introductory matter pertaining to the subject, as this can be obtained by reference to Mr. Ball's work. This introduction includes a summary of the practice of tube milling and the general theories of rock crushing. In all his tests he used the method of efficiency calculation prepared by H. Stadler*, and that method has also been used throughout this paper.

Mr. Ball carried out four series of tests to determine the most efficient conditions for the operation of the tube mill in the laboratory. The factors which he took account of were the rate of feed, the percentage of moisture in the feed, the pebble load and the speed of revolution. He concluded that for each of these factors there was a critical point at which the most efficient work was done, and he believed that he had discovered these points for the laboratory mill in question. His conclusions will be discussed at length later

* Trans. I.M.M., Vol. 19

in this paper in connection with the work done by the author.

Scope of the Investigation.

It is the intention of the Mining Department at McGill to make a thorough investigation of tube milling, as far as it is possible to do so with the equipment which they possess. The work done by Mr. Ball and the author comprises a part of this research, and the experiments made this year were along the following lines:-

(1) Investigation on the Rate of Feed.

(2) " " " Percentage of Moisture in the Feed.
- (a) At constant speed.
- (b) With varying speeds.
- (c) With varying size of feed.

(3) " " " Speed of Revolution.

(4) " " " Size of Feed.

Tests were made on the first three of these points, as it was considered advisable to supplement and check the work that had been previously done. In addition to this a beginning was made on the fourth point, and while it would have been desirable to have made a more complete investigation of this factor it was not possible to do so under the conditions.

Preparation of the Material for the Tests.

It was unfortunate that the laboratory was not able to procure the same kind of rock with which the former tests had been made, viz., nepheline syenite, and this fact must be noted in a comparison of the present results with those obtained in the previous work. The rock used this year was a tinguaite and it is an entirely different type of rock from the syenite.

The preparation of the rock involved a not inconsiderable amount of labour and time, it having to be selected at the quarries, transported to the College and crushed to about 1½" in a Comet crusher.

It was then crushed in a 5 stamp mill (600 pound stamps), the battery screen being changed to give the different sizes of sand used in the tests. The pulp was classified in a Bell conical classifying feeder, and the sands were dried on a steam drying table.

Owing to the fact that the work with the tube mill was not started till the College session was more than half finished, it was not possible to prepare all the material at one time. On this account slight but appreciable variations will be found in sands which should, presumably, be the same. These variations, however, while undesirable are not sufficiently great to vitiate the results.

Description of tube mill and accessory apparatus.

The tube mill was obtained by modifying a discarded chlorination barrel in the Laboratory workshops as follows:-

The lead lining was removed, the trunnions bored out and the interior of the mill was thoroughly scoured out by rotating a charge of dry sand and pebbles. The mill was then completely lined with silex blocks 8" x 4" x 2-1/2" in thickness set in a special cement. All of this material was obtained by Dr. Porter as a donation from The Cyanide Plant Supply Co. of London, Eng.

Flanges were then fastened at the feed, discharge , and manhole openings to strengthen the lining at these points and a perforated steel screen of ample size was placed over the discharge opening.

With the lining in place, the inside dimensions of the mill are as follows:-

Diameter----- 34". Length----- 42". Volume----- 22 cu. ft.

To protect the flange at the manhole and to cover the opening, an inside steel cover plate-curved to the inside diameter of the lining- was used. To this inside cover two bolts are fastened which pass through corresponding openings in the outside manhole cover. Means are provided for holding the inside cover in place while putting on the outside cover, the two being drawn together by tightening two nuts. A gasket under the outside cover effectually prevents any leakage.

The chain and sprocket mill drive was designed by Dr. Porter, the driven sprocket being fastened to the tube mill shell in sections. The driving sprocket is situated on a countershaft which is started and stopped by means of a belt and belt tightener.

The feeder was devised by Prof. Bell to supply the need for a simple form of laboratory feeder capable of delivering dry sand uniformly at any desired rate. It is in effect, simply a very large hour glass, the regularity of the flow depending on the fact that the weight of a mass of sand in a cone is almost entirely carried on the sides of the cone, consequently the sand is discharged at a constant rate whether there is only a few inches or several feet of sand over the discharge opening. This feeder was later developed by Prof. Bell into a combined classifier and feeder in which the settled sands are discharged as quicksands containing from 30% to 40% water but at his suggestion the original form is used in the tube mill tests for the following reasons:-

(a) the rate of flow of dry sand of a given character through a given orifice is almost exactly constant,

(b) by simply adding water in the required amount, pulp of any desired thickness is readily obtainable,

(c) the feed rate and pulp thickness can therefore be easily regulated and maintained with great uniformity throughout each test.

The sand discharged by the feeder falls into an inclined launder where it encounters a water flow regulated to give the required pulp consistency. The water is drawn from a tank provided with an overflow pipe and a slight overflow is maintained to keep the pressure constant. Regulation of the water flow is effected by means of a graduated cock. The inclined launder delivers the partially mixed sand and water to a small hopper fastened to the tube mill standards where it is picked up by a revolving spiral scoop which discharges into the feed trunnion. A complete mixture of the water and sand is effected in the spiral feed hopper but on account of the incomplete mix in the inclined launder it is necessary to constantly scrape the sides to prevent the growth of accretions of damp (very sticky) sand. Prof. Bell has tried a number of modifications of this launder in an endeavour to effect complete mixture in the launder but the present form has proved to be the most satisfactory of all of those tried.

However Mr. Arthur Hannington upon whom not infrequently devolved the rather tedious duty of keeping the launder clear, discovered that by lightly tapping it with the scraper the difficulty was entirely overcome, thus affording additional proof of the relation between necessity and invention. It seems very probable that by mechanically vibrating this launder a complete tube mill experiment could be readily carried out by two men whereas at present three are required.

The following additional improvements (1911-12 tests) have been made to the auxiliary equipment of the mill:-

(1) A spiral feeder replacing the hopper, pipe and stuffing box used in the 1910-11 tests.

(2) An automatic sampler at the discharge end of the mill.

(3) A revolution counter actuated by a cam attached to the feed trunnion. (Available for last nine tests.)

In both the 1911 and 1912 tests, the tendency of the mill to discharge sand and water in gushes was marked, especially at the higher speeds. The automatic sampler of Vezin type was designed by Prof. Bell to minimize the errors in sampling which might accrue as the result of irregular pulp discharge.

The pulp discharged by the mill falls into a small cone fitted with a discharge pipe which is revolving continuously. Once in each revolution the pipe passes over a stationary cutter or trough, delivering pulp to it for a small part of a revolution. The cutter in turn delivers the sample to the sample box. The revolution of the cone is effected by means of a horizontal friction wheel in contact with the end of the discharge trunnion. The reject, or portion of the discharge falling outside the cutter, is delivered to a conical hopper which delivers in turn to a floor tank or to a pump which raises the pulp to a classifier.

The screen analyses of check samples cut out by the sampler are almost identical although the moistures do not check and have a tendency to be about 2% lower than the actual average moisture in the pulp. As the average pulp thickness is easily and accurately determined at the feed end of the mill, this error is not important.

Power and power measurements.

The power for the tube mill was supplied from a 15 H.P. D.C. Crocker Wheeler motor and the measuring instruments used were a D.C. ammeter and voltmeter. Readings were taken at one minute intervals during the final 5 minutes of each test and the gross power used was calculated from the five readings, the assumption being made that the power taken by the tube mill during this time was representative of that being used under the conditions of the test. The mill was then stopped and the power required to turn the motor and shafting at the same speed was observed. The watts input to the motor under the two conditions was then calculated and the corresponding watts output obtained from motor efficiency curves at the various speeds. The nett power used by the tube mill was then obtained by the difference between the two results.

A great deal of trouble was experienced during the experiments owing to the irregularity in the voltage supplied by the college power plant. This was reflected in the speed of the motor which in turn affected the speed of the tube mill and frequently the mill would vary two revolutions per minute in the course of one test. In order to keep the conditions at the tube mill constant, it was necessary to vitiate the power readings by moving the brushes on the motor and this has introduced the possibility of considerable error into the power results. This trouble was encountered only at the normal speed of the mill because at the lower speed tests with a resistance in series with the motor armature, it was possible to keep the voltage constant.

Moreover, at the higher speeds the ammeter needle will fluctuate as much as four amperes due to the irregular load of the mill at these speeds and it was very difficult to obtain correct readings. In fact in the reading of the ammeter alone there is a possible error of at least 15/100 H.P. and in tests such as these, where this amount makes a considerable difference in the results obtained, it would be advisable to use more accurate instruments for measuring the power.

It will be observed that the value of a large part of the work has been nullified owing to difficulties beyond the power of the Mining Laboratory to remedy with the apparatus at its disposal. Admitting the very great difficulty of measuring power with the accuracy desired, the value of the tube mill tests will be enormously enhanced when this difficulty is surmounted therefore the writer would strongly recommend that the power question be given earnest consideration.

The following extracts, from Prof. Bells notes on the 1912 tests, outline desirable experiments and improvements suggested by these tests. "The tendency of the mill to discharge sand and water in gushes may have a marked affect on the grinding. At slow speeds the gushes are barely noticeable but the grinding is much less than at higher speeds on account of the diminished fall of the pebbles. Moreover at the slow speed it was impossible to feed Pulp containing less than 30% water on account of "blocking" in the long feed trunnion, a difficulty which would not be encountered in a standard mill.

For these reasons it would be desirable to experiment with a stationary spiral screw placed in each trunnion, the feed spiral permitting feeding very thick pulp , and the discharge spiral by completely filling the discharge opening, will probably minimize the effect of the "gushes" and deliver an even discharge to the automatic sampler. With an even feed to the sampler it is probable that the moisture in the samples will check with the actual moisture determined at the feed end thus affording an additional check on the accuracy of the work.

It is also probable that check moisture samples would be obtained by increasing the width of the sample cutter to cut out 1/10th instead of 1/25th of the pulp discharged, as at present. Again in view of the possibility that the gushes are caused by masses of pebbles and sand slipping on the inside cover plate which is relatively very smooth as compared with the lining, it would be desirable to see if any improvement was effected by removing this plate and allowing the manhole opening to be fill up with pebbles."

"The difficulties encountered by Mr. Murray in connection with accurately determining the power required by the tube mill under varying conditions have been studied to determine.

the interfering factors, also tests were made with the valuable assistance of Messrs. Murray and Galloway to determine the H.P. output of the motor for various watts input at different voltages.

The interfering factors may be summarized as follows-

1-Line voltage drop.

2- The power house voltage is 220 making it necessary to put the Mining Lab. 115 volt motors on a three wire system permitting sudden and serious fluctuations in the voltage delivered to the motors.

3- The power house voltage regulation while sufficiently close for ordinary conditions is too variable for precise power determinations where the speed and power are so closely related as in the case of a tube mill.

4- the lack of a watt-meter capable of accurately measuring the power used in short time intervals.

While the present motor and power measurement equipment is sufficiently accurate for the regular laboratory work, it is clear that Mr. Murray's pessimism in the matter of his power measurements is well founded and his conservatism in drawing conclusions where the power enters as an important factor is to be commended.

In short, to obtain the full benefit of the valuable work which is being done by the advanced students in ore dressing the difficulties outlined above must be met and overcome.

The installation of the 220 volt motors which Dr. Porter hopes to accomplish in the near future will dispose of one of the most serious difficulties i.e. the 3 wire system necessary under the present conditions.

In this connection also Mr. Murray offers what appears to be a very valuable suggestion by proposing that we do our own voltage regulation by means of a sensitive variable resistance controller situated in the Mining Laboratory. After a careful examination of this proposal I believe it to be the most practicable method for overcoming a large part of the present difficulty, especially in view of the fact that a rheostat is necessary in any case for variable speed tests. Moreover even after the installation of 220 volt motors such an arrangement is almost certain to be desirable by making it possible to control changes in the Central Power Plant voltage due to the varying power demands throughout the University.

With the present equipment it will probably be necessary to adopt the voltage of about 100 and increase the size of the motor pulley to secure the same speed condition which now obtains. The waste of the electrical energy in the rheostat will be more than compensated for by the additional value of the results to be obtained under such favorable conditions.

In this connection it is intercsting to note that the present motor appears to be more efficient at a lower than its rated voltage."

In connection with the power it must ne noted when comparing the author's results with those of Mr. Ball, that he Ball assumed that the efficiency of the motor was 100% in all cases.

Method of Carrying out Tests.

The sands were screened on a 1/8 inch shaking screen before each test to remove any foreign material which might interfere with the regularity of the feed. The material was then weighed in boxes holding about 60 lbs. each, and these were dumped into the feed cone by hand. The sand fed in every test was weighed so as to afford a check on the calibration of the orifice. Every fifth box was retained for a feed sample, and the contents of these boxes were then combined and riffled down to a sample of about five pounds, which was kept for screen analysis.

The previous work had shown that the tube mill conditions became constant after a period of half an hour from the start of a test. This fact was checked at the beginning of this series of experiments and was found to be correct, so that it was decided to make the tests of 40 minutes duration. This was adhered to throughout, with the exception of those tests in which the size of feed was varied in which cases the time was prolonged to 50 minutes as an extra precaution.

The orifice on the feed cone was only changed in the first three tests, so that the calibration of the one used in the majority of the tests was subjected to an excellent checking and the rate of feed for it was determined very accurately at 18 tons per 24 hours.

The weight of water per minute used in each run was checked at the beginning and end of the test and is accurate within one-tenth of one per cent.

Two 5 min. samples of the discharge were taken with the automatic sampler during the last 10 minutes of a test. The one taken during the last five minutes was used for the screen analysis, while the other was kept as a check.

The speed of the mill was checked constantly throughout each test, the addition of the revolution counter making this much easier and more accurate.

Screen Analyses.

The discharge samples were carefully dried on a steam table. In order to prevent the slime from forming in a cake, they were not dried in the boxes in which they were taken but the table was carefully cleaned and the samples were dried directly on its surface. When dry they were riffled down to a convenient weight of about two pounds.

In analysing a discharge sample the product, as prepared above, was carefully mixed on a rubber cloth and a quantity of 150 grams was accurately weighed out on a pulp balance. This weight was then washed on the 200 mesh screen, and what remained on the screen was dried and screen analysed with the automatic screening machine in the laboratory. It was decided to use this method, as otherwise the -200 mesh material tends to blind the 200 mesh screen and makes it necessary to continually knock the screens in order to keep it clear. This subjects them to a considerable amount of hard usage, which can be avoided by employing the above method. This method is more accurate than the "dry" method and does not add greatly to the time required for making the analysis.

As the feed samples only contained about 2% of the -200 grade, it was not necessary to wash them. In analysing the feed sample, on account of the difficulty in obtaining checks by the method used with the discharge, a slightly different procedure was followed. The sample was riffled down to within a few grams of the required weight (130 grams), and the exact weight was then obtained by adding the amount necessary from the original sample mixed on the rubber cloth. The reason for the difference in methods employed was due to the fact that the quantity of slimes in the discharge made it possible to pick up a fair sample with a large spatula. This was not found to be the case with the feed where the larger grains would not be picked up as easily as the smaller, so that a representative screen analysis was not obtained by this method.

The author is not satisfied that the above method of making analyses is free from objection and he would recommend that some work be done on this question of sampling for screen analyses before the actual work with the tube mill is continued next year. The reason for using the method this year was that, in the first place, the author did not have enough time at his disposal to investigate this point, and, secondly, the method used had been employed by Mr. Ball and on that account it was thought desirable to make the conditions of the two investigations similar.

Duplicate analyses of each sample were made and the mean was used in the subsequent calculations.

Screening Machine. Screens etc.

The screening machine was constructed from a drawing based on the description and illustration given in a paper by Mr. T.J. Hoover (Jour. I.M.M. - Vol. 19, p. 506).

To expedite its construction the base of a discarded machine was made use of and simple bushed bearings replaced the ball bearings shown in Mr. Hoover's design. The idea and the mechanism is substantially as outlined by him.

The mechanism imparts an eccentric motion to a nest of screens, which are prevented from revolving by means of outboard springs. In this manner the screens are given exactly the motion which obtains in hand screening and the motion is obviously more continuous and effective.

Laboratory experience in connection with this machine has failed to confirm Mr. Hoover's statement that a complete screen analysis can be effected in 15 minutes, but a period of 30 minutes was chosen as being satisfactory for these tests.

The screens for the machine are 8" diam., mounted on nested circular copper frames 2" deep.

The laboratory possesses two sets of Standard I.M.M. laboratory screens and in the beginning of the tests both sets were used, as considerable time was saved in this manner. Unfortunately, however, it did not take long to find that the 80 mesh screens of the two sets did not have the same aperture. This fact cast some doubt upon the accuracy which is claimed for the screens by the I.M.M. and to settle this point measurements of the screens were made by means of a microscope fitted with a micrometer eye-piece. Twenty to thirty measurements were made on each screen and the following table summarises the results obtained. It will be seen that the average apertures of the screens are very close to the theoretical apertures, and this set of screens was used in all the screen analyses made during the investigation.

Measurements of Laboratory Screens used for Screen Analyses.

Screen	Theoretical Aperture	Ave. of Measurements	Greatest Variation	Theoretical Dia. of Wire	Ave. of Measurements	Greatest Variation	Mechanical Value
	m.	m.	m.	m.	m.	m.	
20 mesh	.0250	.0252	.0228 .0280	.0250	.0248	.0223 .0269	
30 mesh	.0166	.0169	.0163 .0175	.0166	.0166	.0162 .0176	17
50 mesh	.010	.0098	.0093 .0109	.010	.0101	.0095 .0108	19
80 mesh	.0062	.0064	.0055 .0076	.0063	.0060	.0051 .0069	21
120 mesh	.0042	.0042	.0036 .0050	.0041	.0042	.0037 .0045	23
200 mesh	.0025	.0027	.0017 .0037	.0025	.0024	.0019 .0027	25
-200 mesh							28

Mechanical Values of Grades used.

As pointed out by Mr. Stadler in his paper, the grades obtained by using selected I.M.M. screens approximate the standard grades so nearly that no appreciable inaccuracy is introduced in the Calculation of the mechanical values. The values for all the grades, except the +20 mesh, will be found in the table given above. The value for this grade in the feed depended, of course, on the battery screen used. In the case where a 10 mesh screen (.08 in. aperture) was employed, the mechanical value of this grade was calculated from the screen apertures and was found to be 12.8. A determination by weighing 700 grains of this grade, calculating the volume and then the value, gave a figure of 13.1. The mechanical value for the grade in the calculations was taken to be 13.0.

An examination of the +20 grade of the discharge of the tube mill showed that it was considerably finer than the same grade of the feed. A determination of its value was also made and it was found to be very close to 15, and this figure was adopted for the tests at the higher speeds of the tube mill. At the lower speeds, as the amount of +20 mesh sand was in most cases about twice as great as at the high speeds, it was decided to use a value of 14 for this grade. Though an actual determination of this was not made it will, in all probability, be very nearly correct.

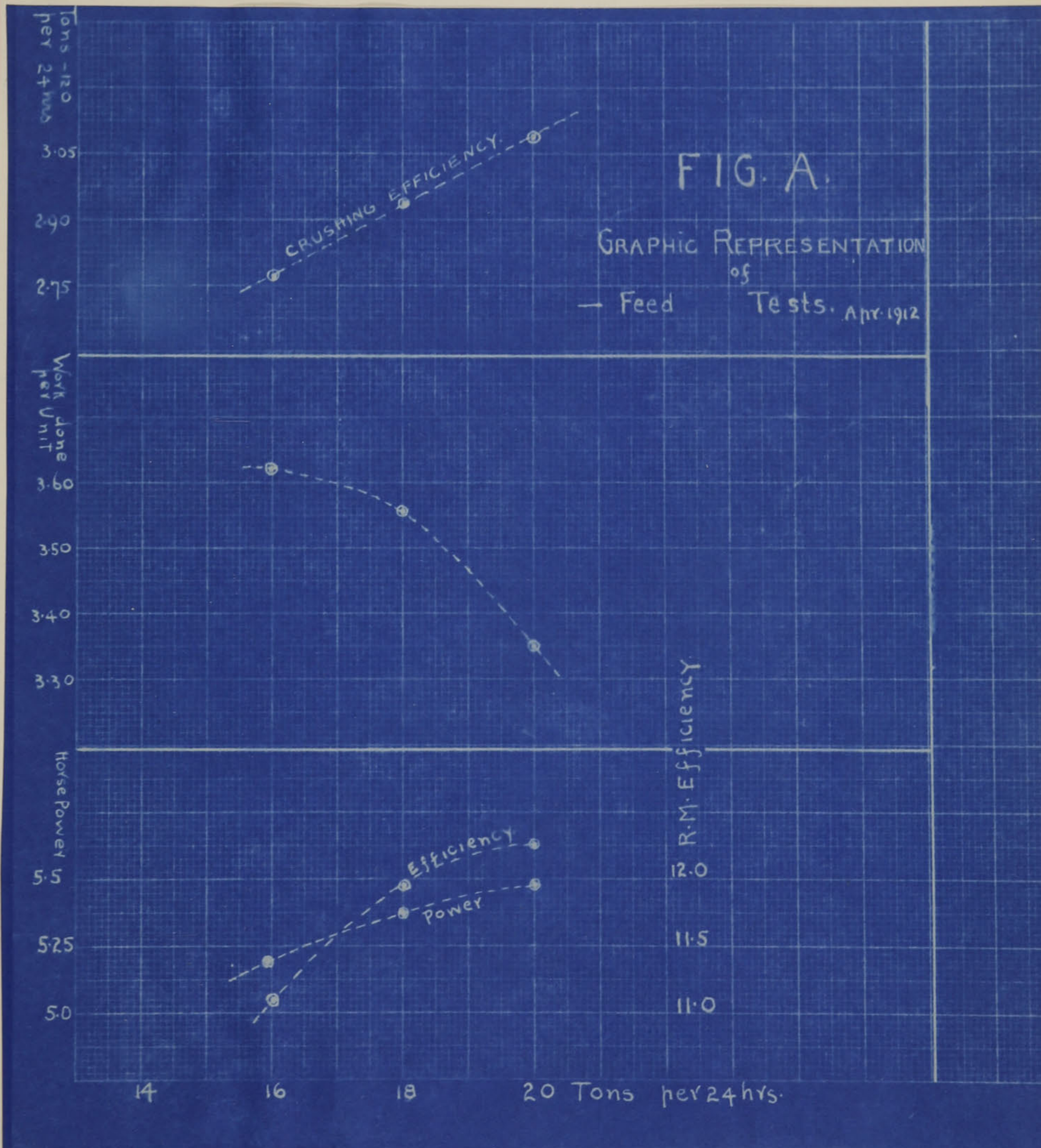
PART. II

TABULATION AND DISCUSSION OF RESULTS.

Series I.

Tests on the Rate of Feed.

The three following tests were run to check the conclusions arrived at by Mr. Ball, that the most efficient rate of feed for the laboratory tube mill was 18 tons per 24 hours.



Feed Tests.
Fig A

Summary of Feed Tests.

Test No.	Character of Feed	Feed Tons per 24 Hours	% Moisture	R.P.M.	Pebble Load	H.P.	Work Done per Unit	-120 Tons 24 hrs.	R.M.E.
1	10 mesh	15.91	37.9	40	lbs. 1050	5.19	3.62	2.78	11.10
2	10 "	18.0	37.7	40	"	5.36	3.56	2.94	11.91
3	10 "	20.0	37.9	40	"	5.47	3.35	3.09	12.25

Mr. Ball made six tests in a similar series but, unfortunately, the test he made at 18 tons per 24 hours was run with 33% moisture whereas the other tests were made with 38%. He claimed, however, that he was able to calculate the effect of this change in moisture and thus to bring this test into line with the others of this series. Whether this be possible or not, and the possibility is far from being evident with the amount of work that has been done, the writer cannot subscribe to Mr. Ball's method of calculation, which was as follows:- From a moisture efficiency* curve made with feed at the rate of 12.6 tons per 24 hours, he obtained the information that between 33% moisture and 38% moisture there was an increase in efficiency from 6.66 to 7.02, a change of .36. Applying this to the results of Test A, which was run at 33% moisture with a feed rate of

* Unless otherwise stated, efficiency means "relative mechanical efficiency per horse power".

18 tons per 24 hours, he states that the efficiency which Test A would have had at 38% moisture may be obtained from the simple proportion calculation:-

12.6 : 18.6 :: .36 : x   and x = the increase in efficiency at 18 tons = .53

Putting this into words, "One rate of feed is to another rate of feed as the change in efficiency due to a change of moisture at the first rate is to the change in efficiency due to the same change in moisture at the second rate of feed." The writer can see no grounds for this statement, taking the assumption, as Mr. Ball did, that the moisture efficiency curves would have the same form for each rate of feed.

A more logical method of calculation would seem to be that with this assumption the percentage change in efficiency would be the same in each case. If this is done, the change comes out to be .42 instead of .53, and the efficiency at 18 tons per 24 hours and 38% would be 8.18 instead of 8.29 by the first method of calculation.

Considerable doubt, however, must be attached to the accuracy of the results from calculations such as these, because, as Mr. S.J. Truscott has pointed out in his criticism of Mr. Ball's paper, by applying the information from the moisture-power curve given in Ball's paper and correcting the horse power of Test A mentioned above, it will be found that the corrected horse power is 4.65 whereas, to fit in with the results of the other tests, it should be about 5.85.

Examining the results from the three experiments made by the writer, the following points will be observed:-

1. The work done per unit decreases with the increased rate of feed. This is in line with practice where the finest crushing is done with the smallest rates of feed.

2. The horse power increases with the increased rate of feed. This conclusion is subject to the doubt as to the accuracy of these readings, but as this result is in line with previous work it will be taken that it is true in this case.

3. While the work done per unit is decreasing and the power is increasing, still the efficiency becomes greater as the rate of feed increases. It would seem that the most efficient rate would be about 20 tons per 24 hours under the conditions of these tests.

4. The tonnage of -120 grade produced, an important point in mills where fine grinding is necessary, is increasing with the rate of feed, and the results would indicate that the maximum would be obtained at a still higher rate.

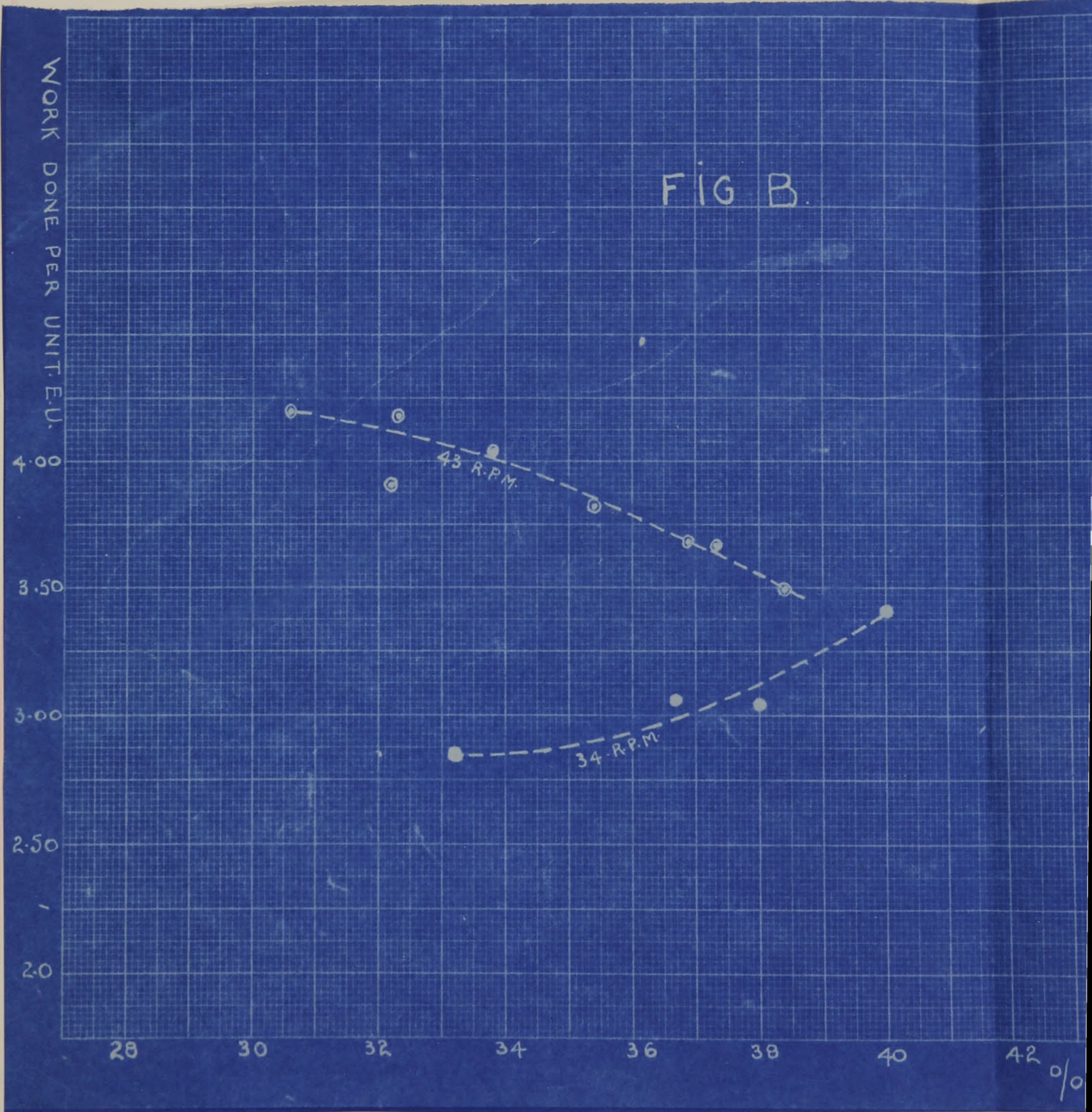


FIG B.
WORK DONE PER UNIT E.U.
4.00
3.50
3.00
2.50
2.0
43 R.P.M.
34 R.P.M.
28
30
32
34
36
38
40
42
o/o

Series II.

Tests on the Effect of Variations in the Percentage of Moisture.

(a) At Constant Speeds.
(b) At Varying Speeds.
(c) With different Size of Feed.

PEBBLE LOAD 1050 lbs.
RATE OF FEED 18 tons per 24hrs

Summary of Tests.

Test No.	Character of Feed	% Moisture	R.P.M.	H.P.	Work done per Unit	-120 grade Tons 24 hrs.	R.M.E.
4	10 mesh	38.4	43	5.77	3.50	2.80	10.90
5	"	37.3	43	5.50	3.67	2.91	12.00
6	"	36.9	43	5.37	3.68	2.93	12.31
7	"	35.4	43	5.35	3.81	3.16	12.80
8	"	33.8	43	5.04	4.03	3.38	14.40
9	"	32.2	43	5.57	3.90	3.50	12.60
10	"	32.3	43	5.75	4.18	3.30	13.06
11	"	30.6	43	5.40	4.20	4.07	13.97
12	18 mesh	34.2	43	5.67	2.40	3.16	7.62
13	"	36.2	43	5.65	2.47	3.39	7.85
14	"	38.0	43	5.18	2.43	3.12	8.45
15	"	38.2	43	5.85	2.34	2.92	7.21
16	"	40.5	43	5.67	2.56	3.76	8.12
17	10 mesh	33.2	34	4.17	2.88	2.15	12.45
18	"	36.7	34	4.39	3.06	2.24	12.55
19	"	38.0	34	4.27	3.04	2.32	12.80
20	"	40.5	34	4.47	3.40	2.44	13.65

From other experiments made on this question of the effect of moisture, it had generally been concluded that a pulp containing from 38 to 40 per cent water was the most desirable to feed to tube mills. In the experiments carried on at McGill in 1911, it was believed that 37.7% was the most efficient condition. The author of this paper, however, does not believe that any definite conclusions can be drawn from the results of his experiments. This is, for the most part, due to the lack of confidence in the power readings. It had been hoped that by making the variations over a comparatively small range more definite conclusions could be drawn, but this hope has not been realised.

If the horse power required to operate the mill under the varying conditions be examined, it will be seen that the variations in power are considerable for slight changes but that these variations are, for the most part, not greater than the possible error. For instance, Tests 9 and 10 are made under approximately the same conditions and yet the horse power in Test 9 is 5.57, whereas in Test 10 it is 5.75.

The results show that with the coarser feed the least power is taken in the neighbourhood of 34% moisture. At 43 R.P.M. this corresponds with the point of greatest efficiency, but at 34 R.P.M. the efficiency is greatest at 40.5% moisture.

The five tests on the finer feed show that if the horse power for Test 14 is correct, it is possible that for this size of feed the least power is taken at 38% moisture, but this will have to be proven by further experimenting.

Comparing the results of the tests with the two series, it will be noticed that a variation in moisture does not affect the work done on the finer size as much as a corresponding change affects the work done on the coarser size.

By examining the work done per unit some interesting facts will be noticed. It will be observed that at 43 R.P.M. the work done is increasing steadily with a decrease in the moisture from 38% to 30%. This fact is brought out clearly by reference to Fig. B, plotted from the figures. An attempt was made to run an experiment with 28% moisture, but with the present feeding device it was not found possible to experiment with such a low moisture, as the trunnion became blocked with sand, so that the limit of this increase was not obtained.

The results of Tests 17-20, with the same feed at 34 R.P.M., seem to indicate that the work done per unit is increasing with the increase in the percentage of moisture. With only four tests, however, at this speed it must not be considered that this point is settled.

If further work confirms the results of these four tests, it will be seen that the effect of a change in moisture is not the same at different speeds. At the higher rate of revolution the best results would be obtained with a lower moisture than that which would give the best results at a lower rate. Mr. S.J. Truscott* cites a case which would seem to bear out this conclusion. He says that at the Komata Reefs in New Zealand they use a speed which is considerably less than on the Rand, and they find that a moisture of about 50% is the one that gives them the greatest efficiency. The Rand practice is to use about 38% moisture, so that it looks as though the speed might account for this difference.

The five tests on the 18 mesh sand also show an increase in work done per unit with an increase in moisture, and though the time did not suffice for more experiments in this series these results would show that the character of the feed also affects the critical moisture.

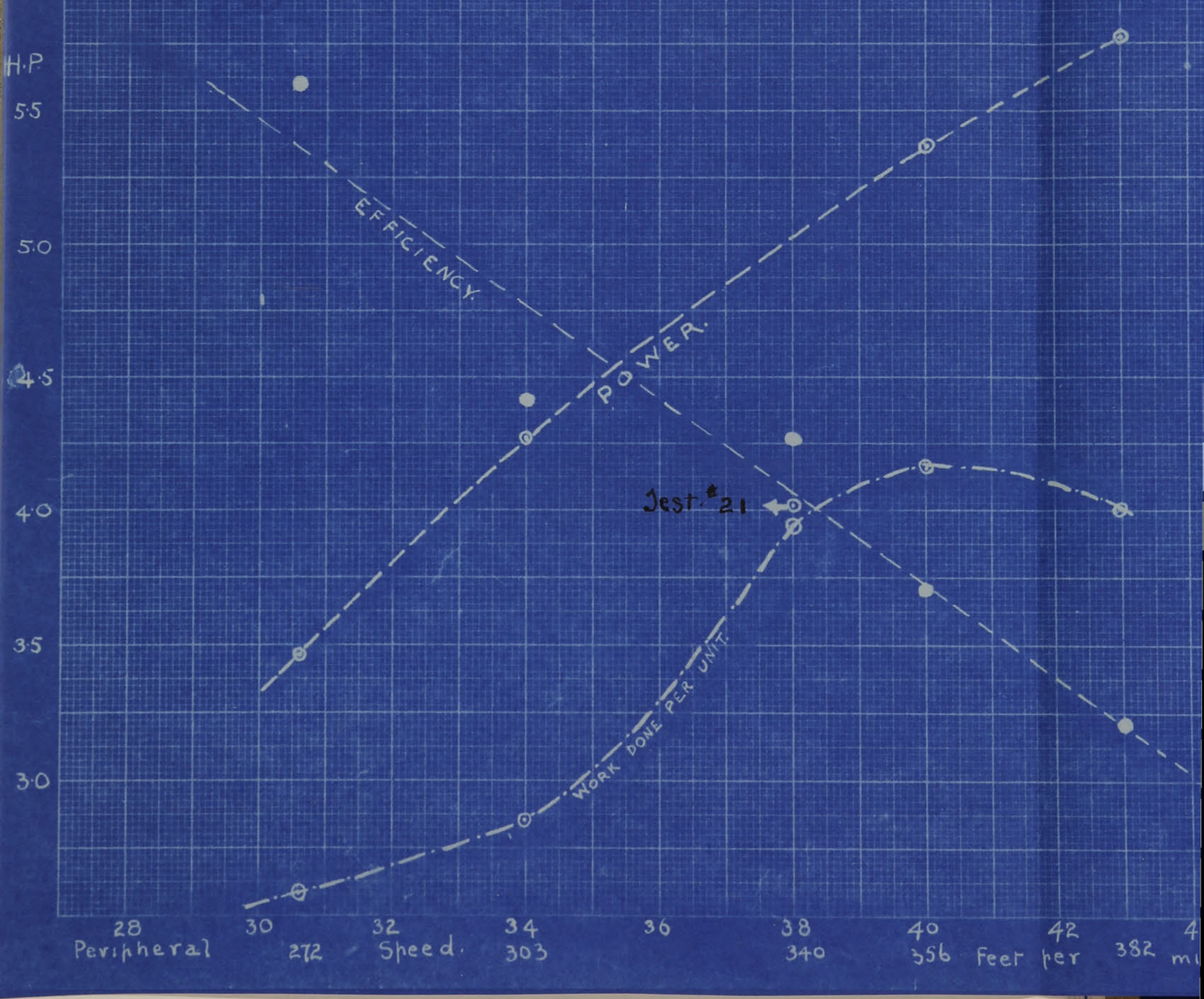
Series III.

Speed Tests.

Five tests were made in this series with constant moisture, pebble load, size and rate of feed.

* Bull. No. 86, I.M.M., 1911.

FIG. C.


H.P.
5.5
5.0
4.5
4.0
3.5
3.0
EFFICIENCY.
POWER.
WORK DONE PER UNIT.
Test #21
28
30
32
34
36
38
40
42
Peripheral
272
Speed.
303
340
356
Feet per
382

Summary of Tests.

Test No.	R.P.M.	H.P.	Work done per Unit	-120 Tons per 24 hours	R.M.E.	
4	43	5.77	3.50	2.80	10.90	Pebble Load, 1050 lbs.
2	40	5.36	3.56	2.94	11.91	
21	38	4.01(?)	3.48	2.42	15.59(?)	10 Mesh Sand.
19	34	4.27	3.04	2.32	12.80	Rate = 18 tons per 24 hours.
22	30.6	3.48	2.94	2.01	15.20	Moisture, approx. 38%

The normal speed of the motor gave 43 R.P.M. at the tube mill, so in order to decrease the speed a resistance was put in series with the armature, and to obtain the diffèrent speeds for the tests the amount of resistance in the circuit was varied.

The variations in power do not affect the general conclusions which may be drawn from this series of tests, on account of the fact that there is a comparatively large difference in the quantity of power used in the experiments.

An examination of Fig. C, which graphically represents the results of these tests, shows that the power to operate the mill increases with the rate of revolution. Test 21 at 38 R.P.M. does not come on the power curve in the figure, but this is evidently due to some error in the power readings for this test, as the form of curve sketched in agrees with the results obtained by the previous experiments made between 37 and 46 R.P.M. In plotting the efficiency for Test 21 in this figure the power was taken from the curve to be approximately 5 H.P., and this is the figure that has been used in calculating the plotted efficiency for this case.

In the experiments made by Mr. Ball on the speed factor, he considered that he had found that below 37 R.P.M. there was an increase in the power required to turn the mill. When the results of the author's tests were found to differ so radically from this conclusion, an investigation into the cause of the difference has shown that through an error in connecting the voltmeter to the switchboard instead of to the brushes of the motor in Mr Ball's tests the energy lost in the resistance was calculated as having been used by the motor, so that the results he obtained at slower speeds than 37 R.P.M. are not correct. This incorrectness is, of course, reflected in the relative mechanical efficiency, and on that account the author's experiments have altered the whole aspect of the situation.

From the conclusions that could be drawn from the previous (1910-11) results, it was manifestly absurd to use a slower speed of revolution than that giving a certain peripheral speed, because not only did the grinding decrease markedly but the power required in the operation increased. With the new light that has been thrown on this question by these later experiments, however, it will be seen that while the grinding is less the lower the speed of revolution, the power decreases also, so that the highest relative mechanical efficiency was obtained at the lowest speed on which an experiment was made. In deciding ~~on~~ the most desirable speed for any particular case, it becomes a question of balancing these factors. In the case of an ore in which a very fine state of comminution is not necessary, or in a case where the power costs are excessive, it would seem that low speeds would be economical.

The tests in this series were all made with approximately 38% moisture, and the work done per unit with pulp of this character is shown in Fig. C. Another factor, however, must be remembered, viz., that the effect of the same moisture may not be the same at different speeds. For instance, the work done per unit at 34 R.P.M. and 40.5% moisture (Test 20) is nearly as great as that done at 43 R.P.M. and 38% moisture (Test 4), but it is considerably less than that done at 43 R.P.M. and lower moistures.

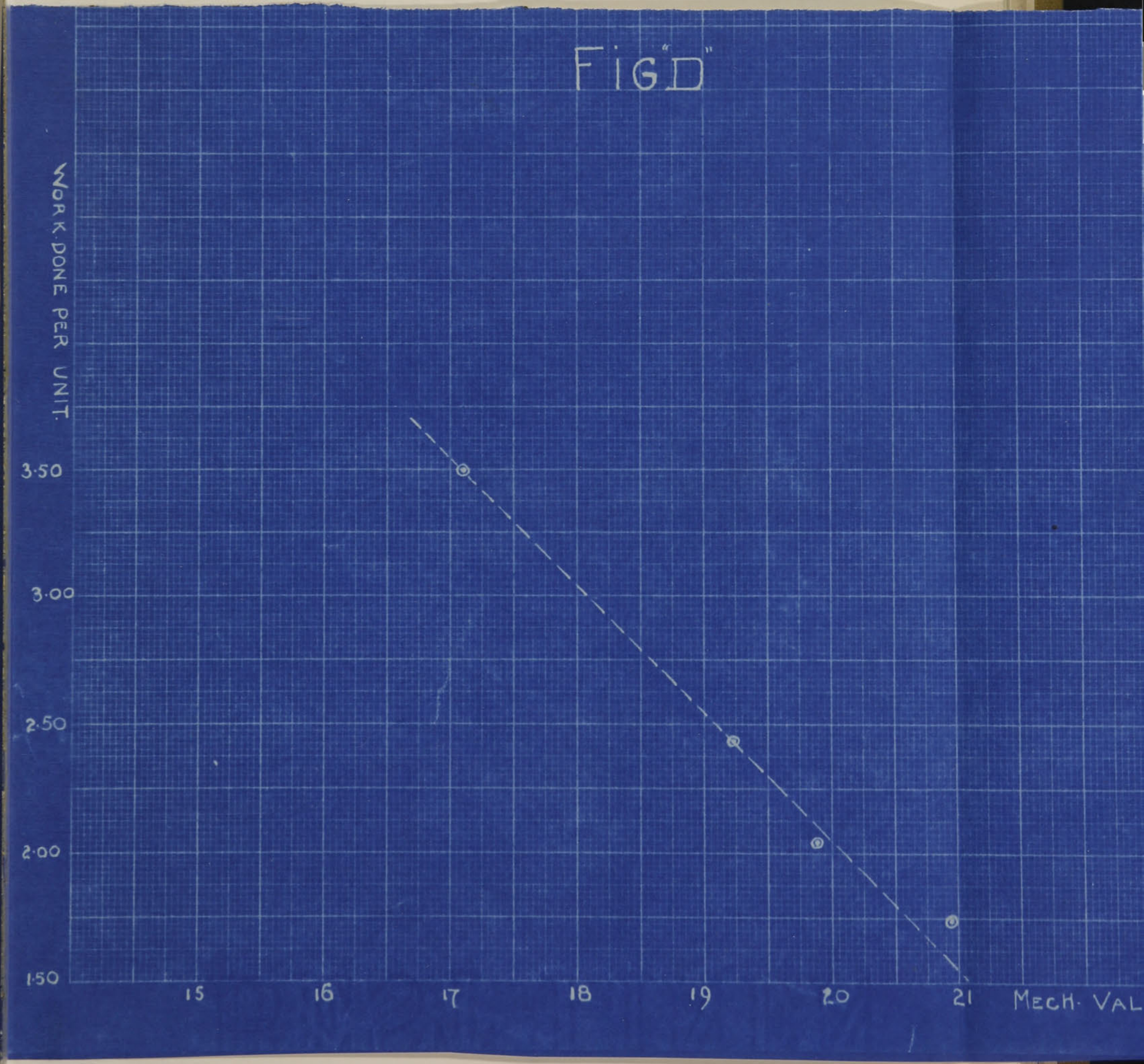


FIG "D"
WORK DONE PER UNIT.
3.50
3.00
2.50
2.00
1.50
15
16
17
18
19
20
21
MECH. VAL

Through an error the wrong curve was this sheet. The correct one will be inserted here later.

GBM

Series IV.

Size of Feed to the Tube Mill.

Summary of Tests.

Test No.	M.V. of Feed	Feed, Tons 24 hours	Mois-ture	H.P.	Work done per Unit	-120, Tons per 24 hrs.	R.M.E.
4	17.14	18.0	38.4	5.77	3.50	2.80	10.90
14	19.24	18.0	38.0	5.18	2.43	3.12	8.45
23	19.89	18.0	38.0	4.84	2.04	2.76	7.60
24	20.92	16.8	39.6	5.35	1.73	3.01	5.43

R.P.M. 43, Pebble Load 1050 lbs.

The feed for Test 23 was prepared by desliming the tube mill discharge on 10 mesh sand; that for Test 24 was made by desliming the sand crushed in a a Huntingdon mill fitted with a 30 mesh screen.

In Test 24 the same orifice was used on the feed cone as in the previous tests, but it will be seen that this fine sand did not feed at as fast a rate as the coarse and on that account the moisture in this test is 39.6%, due to the fact that the water used was calculated before the test for a feed rate of 18 tons.

The results show in a striking manner the decrease in the amount of work done with the increased mechanical value of the feed, and even with the 34" diam. mill it is evident that a still coarser feed would be more efficient. In this connection it will be of interest to note the increase in work done per unit with nepheline syenite under similar conditions. The test on the coarse sand was made by the 4th. Year students in a laboratory run, while the figures for the fine sand are taken from Test V made by Mr. Ball.

Character of Rock:- Nepheline syenite, coarse size = 10 mesh battery screen
fine " = 18 " " "

M.V. of Feed	R.P.M.	Moisture	Pebble Load	Work per Unit
19.59	37	37.7%	1030 lbs.	2.45
18.13	40	38.0%	1050 "	3.72

Feed 18 tons per 24 hours.

These tests, while not made under identical conditions, also show an increase in efficiency with the coarse size.

Lack of time prevented further tests being made in this series, but it is evident from the curve (Fig. D), plotted from results obtained in the tests, that the coarse feed to the tube mill has raised the efficiency in a marked manner, and these results would indicate that even the four mesh battery screens now used in Rand practice may be replaced by ones with even larger apertures. This indication is a considerable advance from the theory held by Argall, according to Richards*, in which he states that the most economical size of feed

* Text Book of Ore Dressing.

to the tube mill is .02 in., and it is in line with the opinion that has already been advanced by a number of engineers on the Rand in this connection.

General Conclusions.

In the first series of tests on the rate of feed while the most efficient rate has not been definitely determined, it would appear to be fairly close to 20 tons per 24 hours for this rock and this size of feed. In regard to the tonnage of -120 mesh produced, with the 18 mesh nepheline syenite sand Ball concluded that the critical point was at 20 tons per 24 hours, but he included the figures obtained from a test at 33% moisture in a series made at 38% moisture, and it is questionable whether he was justified in doing this. In any case, it appears that under the condition of the author's tests the tonnage of fine sand per 24 hours is increasing with the rate of feed, and it will be worth while to find out whether the critical point for this crushing efficiency differs materially from the critical point obtained from a consideration of the relative mechanical efficiency.

The tests in Series II., on the effect of variations in the moisture, did not prove as satisfactory as had been expected for reasons stated previously. They have indicated, however, that the effect of a change in moisture may depend upon the speed of revolution.

The conclusions arrived at in the speed tests are directly opposed to those made from the results of the former tests at McGill, and it will be interesting to continue this series at lower rates of revolution to find out the effect of the decreased power on the efficiency. Within the limits of this investigation, the effect of increased speed is to lower the relative mechanical efficiency per horse power of the operation but to increase the amount of grinding done.

The tests in Series IV. were the most interesting in the work. They have shown that the practice of increasing the size of feed above the limit first used in tube milling is justified by the facts, and although, with the small laboratory mill, the maximum size of particle which it is possible to crush economically in the standard mills cannot be determined, still some valuable deductions can be made when these tests are continued with coarser feeds.

A series of tests with the fine sizes would be of interest also, in view of the opinion advanced by Prof. Bell that it would possibly be more economical to treat the tube mill "returns" in a separate mill which was more suitably adjusted to deal with them. In making such an investigation, the author would suggest that the first experiments be made on the speed of revolution. It is usually considered that the grinding in the tube mill is the result of two different kinds of crushing, viz., impact and abrasion. The tests made on the fine sizes in this investigation were made with speeds which would give more of the first kind of crushing, and while this is favourable to efficient results with the coarse feeds, it is possible that if tests had been made at lower speeds the grinding in the fine sizes would have been increased. This is a point, however, that, along with many other debatable questions, will probably be settled in the continuation of the tube milling experiments, for perhaps one of the outstanding features of the work done in the Mining Laboratory this year has been the fact that it has clearly shown the large amount of work that still remains to be done.along this line.

In conclusion, the author wishes to express his thanks to Dr. Porter, the Director of the Mining Department, for advice in connection with the work, and also to Messrs. Gartshore, Hanington and Raymond for assistance in carrying out the tests. He wishes especially, however, to thank Prof. J.W. Bell not only for the actual time spent in assisting in the work but also for the many valuable ideas advanced by him in the discussion of the investigation.

PART 111.

DETAILED

~~Delaid~~ Results of Tests including screen analyses etc.

Tube Mill Efficiency Test.

Date. Feb. 5th 1912		Test Number. 1	
Dry Feed- 24 hours. 15.91 Tons.		Water in pulp. 37.9	%
R. P. M. 40		* Pebble Load. 1050	Lbs.
Mechanical value of Discharge		20.88	E.U.
Mechanical value of Feed.		17.26	E.U.
Work done per unit.		3.62	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		5.19	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		11.10	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.			
Grade.	%	E.U.	M.V.
+ 20	37.31	13	4.85
30	19.00	17	3.23
50	19.05	19	3.62
80	13.55	21	2.85
120	5.73	23	1.31
200	3.28	25	.82
- 200	2.08	28	.58
Total	100.00		17.26

Discharge.			
Grade.	%	E.U.	M.V.
+ 20	9.40	15	1.41
30	15.87	17	2.70
50	22.75	19	4.32
80	22.14	21	4.65
120	7.04	23	1.62
200	6.93	25	1.73
- 200	15.87	28	4.45
Total	100.00		20.88

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	2.78
Tons - 200 grade produced in 24 hours.	2.20

* The Pebbles used were "Danish Flint Pebbles" obtained from the Canada Cement Co.

Tube Mill Efficiency Test.

Date. Feb. 5th 1912.	Test Number. 2	
Dry Feed- 24 hours. 18·0 Tons.	Water in pulp. 37·7	%
R. P. M. 40	Pebble Load. 1050	Lbs.

Mechanical value of Discharge	20·82	E.U.
Mechanical value of Feed.	17·26	E.U.
Work done per unit.	3·56	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.	5·36	H.P.
Deduct Mill Friction	—	H.P.
Nett Power - Raising pebbles and pulp	—	H.P.
Relative Mechanical Efficiency based on Gross Power.	11·91	
Relative Mechanical Efficiency based on Nett Power.	—	

Screen Analyses.

Feed.			
Grade.	%	E.U.	M.V.
+ 20	37·31	13	4·85
30	19·00	17	3·23
50	19·05	19	3·62
80	13·55	21	2·85
120	5·73	23	1·31
200	3·28	25	·82
- 200	2·08	28	·58
Total	100·00		17·26

Discharge.			
Grade.	%	E.U.	M.V.
+ 20	9·96	15	1·50
30	16·05	17	2·73
50	23·28	19	4·43
80	20·01	21	4·22
120	8·97	23	2·07
200	7·20	25	1·80
- 200	14·53	28	4·07
Total	100·00		20·82

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	2·94
Tons - 200 grade produced in 24 hours.	2·24

Tube Mill Efficiency Test.

Date. Feb. 5th 1912	Test Number.	3	
Dry Feed- 24 hours. 20 Tons.	Water in pulp.	37.9	%
R. P. M. 40	Pebble Load.	1050	Lbs.
Mechanical value of Discharge		20.61	E.U.
Mechanical value of Feed.		17.26	E.U.
Work done per unit.		3.35	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		5.47	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		12.25	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.			
Grade.	%	E.U.	M.V.
+ 20	37.31	13	4.85
30	19.00	17	3.23
50	19.05	19	3.62
80	13.55	21	2.85
120	5.73	23	1.31
200	3.28	25	.82
- 200	2.08	28	.58
Total	100.00		17.26

Discharge.			
Grade.	%	E.U.	M.V.
+ 20	11.48		1.72
30	16.78	17	2.86
50	23.00	19	4.36
80	19.32	21	4.06
120	8.60	23	1.98
200	6.88	25	1.72
- 200	13.94	28	3.91
Total	100.00		20.61

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	3.09
Tons - 200 grade produced in 24 hours.	2.37

Tube Mill Efficiency Test.

Date. March 1st 1912		Test Number. 4.	
Dry Feed- 24 hours. 18 Tons.		Water in pulp. 38.4	%
R. P. M. 43		Pebble Load. 1050.	Lbs.
Mechanical value of Discharge		20.64	E.U.
Mechanical value of Feed.		17.14	E.U.
Work done per unit.		3.50	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		5.77	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		10.90	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.			
Grade.	%	E.U.	M.V.
+ 20	39.50	13	5.14
30	18.95	17	3.21
50	17.50	19	3.33
80	13.00	21	2.73
120	5.58	23	1.29
200	3.27	25	.82
- 200	2.20	28	.62
Total	100.00		17.14

Discharge.			
Grade.	%	E.U.	M.V.
+ 20	11.10	15	1.65
30	17.05	17	2.90
50	23.35	19	4.45
80	19.00	21	3.99
120	8.50	23	1.95
200	5.98	25	1.50
- 200	15.02	28	4.20
Total	100.00		20.64

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	2.80
Tons - 200 grade produced in 24 hours.	2.31

Tube Mill Efficiency Test.

Date. Feb 18th 1912		Test Number. 5		
Dry Feed- 24 hours. 18 Tons.		Water in pulp. 37.3		%
R. P. M. 43.		Pebble Load. 1050		Lbs.
Mechanical value of Discharge			20.93	E.U.
Mechanical value of Feed.			17.26	E.U.
Work done per unit.			3.67	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.			5.50	H.P.
Deduct Mill Friction			—	H.P.
Nett Power - Raising pebbles and pulp			—	H.P.
Relative Mechanical Efficiency based on Gross Power.			12.00	
Relative Mechanical Efficiency based on Nett Power.			—	

Screen Analyses.

Feed.			
Grade.	%	E.U.	M.V.
+ 20			
30		17	
50		19	
80		21	
120		23	
200		25	
- 200		28	
Total			

Discharge.			
Grade.	%	E.U.	M.V.
+ 20	9.25	15	1.39
30	15.75	17	2.78
50	24.65	19	4.70
80	20.25	21	4.25
120	8.60	23	1.98
200	6.50	25	1.63
- 200	15.00	28	4.20
Total	100.00		20.93

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	2.91
Tons - 200 grade produced in 24 hours.	2.30

Tube Mill Efficiency Test.

Date. Feb 18th 1912	Test Number. 6		
Dry Feed- 24 hours. 18 Tons.	Water in pulp. 36.9		%
R. P. M. 43	Pebble Load. 1050		Lbs.
Mechanical value of Discharge		20.94	E.U.
Mechanical value of Feed.		17.26	E.U.
Work done per unit.		3.68	E.U.
Gross power = Mill Friction plus Pebbles plus Pulp.		537	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		12.31	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.

Grade.	%	E.U.	M.V.
+ 20			
30		17	
50		19	
80		21	
120		23	
200		25	
- 200		28	
Total			

Discharge.

Grade.	%	E.U.	M.V.
+ 20	9.38	15	1.42
30	16.12	17	2.84
50	24.05	19	4.58
80	20.15	21	4.25
120	8.67	23	2.00
200	6.38	25	1.59
- 200	15.25	28	4.26
Total	100.00		20.94

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	2.93
Tons - 200 grade produced in 24 hours.	2.37

Tube Mill Efficiency Test.

Date. March 1912		Test Number. 7	
Dry Feed- 24 hours. 18 Tons.		Water in pulp. 35.4	%
R. P. M. 43		Pebble Load. 1050	Lbs.
Mechanical value of Discharge		20.95	E.U.
Mechanical value of Feed.		17.14	E.U.
Work done per unit.		3.81	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		5.35	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		12.80	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.

Grade.	%	E.U.	M.V.
+ 20	39.50	13	5.14
30	18.95	17	3.21
50	17.50	19	3.33
80	13.00	21	2.73
120	5.58	23	1.29
200	3.27	25	.82
- 200	2.20	28	.62
Total	100.00		17.14

Discharge.

Grade.	%	E.U.	M.V.
+ 20	9.30	15	1.40
30	15.65	17	2.67
50	22.95	19	4.36
80	19.85	21	4.16
120	9.25	23	2.13
200	6.70	25	1.67
- 200	16.30	28	4.56
Total	100.00		20.95

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	3.16
Tons - 200 grade produced in 24 hours.	2.54.

Tube Mill Efficiency Test.

Date. Mar. 6th 1912		Test Number. 8	
Dry Feed - 24 hours. 18 Tons.		Water in pulp. 33.8	%
R. P. M. 43		Pebble Load. 1050	Lbs.
Mechanical value of Discharge		21.17	E.U.
Mechanical value of Feed.		17.14	E.U.
Work done per unit.		4.03	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		5.04	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		14.40	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.			
Grade.	%	E.U.	M.V.
+ 20	39.50	13	5.14
30	18.95	17	3.21
50	17.50	19	3.33
80	13.00	21	2.73
120	5.58	23	1.29
200	3.27	25	.82
- 200	2.20	28	.62
Total	100.00		17.14

Discharge.			
Grade.	%	E.U.	M.V.
+ 20	8.15	15	1.22
30	14.50	17	2.46
50	23.05	19	4.38
80	20.60	21	4.34
120	9.45	23	2.18
200	6.75	25	1.69
- 200	17.50	28	4.90
Total	100.00		21.17

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	3.38
Tons - 200 grade produced in 24 hours.	2.76

Tube Mill Efficiency Test.

Date. Mar 11th 1912	Test Number. 9		
Dry Feed- 24 hours. 18 Tons.	Water in pulp. 32.2		%
R. P. M. 43	Pebble Load. 1050		Lbs.
Mechanical value of Discharge		21.04	E.U.
Mechanical value of Feed.		17.14	E.U.
Work done per unit.		3.90	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		5.57	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		12.60	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.

Grade.	%	E.U.	M.V.
+ 20	39.50	13	5.14
30	18.95	17	3.21
50	17.50	19	3.33
80	13.00	21	2.73
120	5.58	23	1.29
200	3.27	25	.82
- 200	2.20	28	.62
Total	100.00		17.14

Discharge.

Grade.	%	E.U.	M.V.
+ 20	11.46	15	1.72
30	15.43	17	2.65
50	20.61	19	3.92
80	18.50	21	3.88
120	9.07	23	2.08
200	6.88	25	1.72
- 200	18.05	28	5.07
Total	100.00		21.04

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	3.50
Tons - 200 grade produced in 24 hours.	2.86

Tube Mill Efficiency Test.

Date. March 20th 1912		Test Number. 10	
Dry Feed - 24 hours. 18 Tons.		Water in pulp. 32.3	%
R. P. M. 43		Pebble Load. 1050	Lbs.
Mechanical value of Discharge		20.79	E.U.
Mechanical value of Feed.		16.61	E.U.
Work done per unit.		4.18	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		5.75	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		13.06	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.			
Grade.	%	E.U.	M.V.
+ 20	45.10	13	5.86
30	18.85	17	3.21
50	15.89	19	3.02
80	11.73	21	2.46
120	4.63	23	1.07
200	2.52	25	.63
- 200	1.28	28	.36
Total	100.00		16.61

Discharge.			
Grade.	%	E.U.	M.V.
+ 20	10.90	15	1.64
30	16.30	17	2.77
50	22.20	19	4.22
80	19.50	21	4.10
120	9.00	23	2.07
200	6.35	25	1.64
- 200	15.55	28	4.35
Total	100.00		20.79

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	3.30
Tons - 200 grade produced in 24 hours.	2.57

Tube Mill Efficiency Test.

Date. Mar 11th 1912		Test Number. 11	
Dry Feed- 24 hours. Tons.		Water in pulp. 30·6	%
R. P. M. 43.		Pebble Load. 1050	Lbs.
Mechanical value of Discharge		21·34	E.U.
Mechanical value of Feed.		17·14	E.U.
Work done per unit.		4·20	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		5·40	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		13·97	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.

Grade.	%	E.U.	M.V.
+ 20	39·50	13	5·14
30	18·95	17	3·21
50	17·50	19	3·33
80	13·00	21	2·73
120	5·58	23	1·29
200	3·27	25	·82
- 200	2·20	28	·62
Total	100·00		17·14

Discharge.

Grade.	%	E.U.	M.V.
+ 20	9·34	15	1·40
30	14·02	17	2·39
50	19·90	19	3·79
80	19·04	21	4·00
120	9·60	23	2·21
200	7·20	25	1·80
- 200	20·90	28	5·75
Total	100·00		21·34

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	4·07
Tons - 200 grade produced in 24 hours.	13·47

Tube Mill Efficiency Test.

Date. Mar 18th 1912	Test Number. 12		
Dry Feed- 24 hours. 18 Tons.	Water in pulp.	34.2	%
R. P. M. 43	Pebble Load.	1050	Lbs.
Mechanical value of Discharge		21.67	E.U.
Mechanical value of Feed.		19.27	E.U.
Work done per unit.		2.40	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		5.67	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		7.62	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.

Grade.	%	E.U.	M.V.
+ 20	13.31	15	2.00
30	23.77	17	4.04
50	25.83	19	4.92
80	20.18	21	4.23
120	8.76	23	2.02
200	5.18	25	1.22
- 200	2.97	28	.84
Total	100.00		19.27

Discharge.

Grade.	%	E.U.	M.V.
+ 20	3.07	15	.46
30	11.83	17	2.02
50	23.90	19	4.54
80	24.23	21	5.10
120	11.24	23	2.58
200	7.97	25	1.99
- 200	17.76	28	4.98
Total	100.00		21.67

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	3.16
Tons - 200 grade produced in 24 hours.	2.66.

Tube Mill Efficiency Test.

Date. May 18th 1912		Test Number. 13	
Dry Feed- 24 hours. 18 Tons.		Water in pulp. 36.2	%
R. P. M. 43		Pebble Load. 1050	Lbs.
Mechanical value of Discharge		21.81	E.U.
Mechanical value of Feed.		19.34	E.U.
Work done per unit.		2.47	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		5.65	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		7.85	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.

Grade.	%	E.U.	M.V.
+ 20	12.45	15	1.86
30	23.67	17	4.02
50	26.63	19	5.06
80	20.64	21	4.34
120	8.85	23	2.04
200	4.92	25	1.23
- 200	2.84	28	.79
Total	100.00		19.34

Discharge.

Grade.	%	E.U.	M.V.
+ 20	2.81	15	.42
30	11.10	17	1.90
50	23.45	19	4.46
80	24.65	21	5.19
120	11.42	23	2.64
200	8.07	25	2.02
- 200	18.50	28	5.18
Total	100.00		21.81

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	3.40
Tons - 200 grade produced in 24 hours..	2.82

Tube Mill Efficiency Test.

Date. Apr 2, 1912.		Test Number. 14		
Dry Feed- 24 hours. Tons.		Water in pulp.	38·0	%
R. P. M. 43		Pebble Load.	1050	Lbs.
Mechanical value of Discharge			21·67	E.U.
Mechanical value of Feed.			19·24	E.U.
Work done per unit.			2·43	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.			5·18	H.P.
Deduct Mill Friction			—	H.P.
Nett Power - Raising pebbles and pulp			—	H.P.
Relative Mechanical Efficiency based on Gross Power.			8·45	
Relative Mechanical Efficiency based on Nett Power.			—	

Screen Analyses.

Feed.

Grade.	%	E.U.	M.V.
+ 20	13·70	15	2·06
30	25·70	17	4·37
50	24·65	19	4·67
80	19·15	21	4·02
120	8·30	23	1·91
200	5·45	25	1·36
- 200	3·05	28	·85
Total	100·00		19·24

Discharge.

Grade.	%	E.U.	M.V.
+ 20	3·10	15	·44
30	11·80	17	2·05
50	24·10	19	4·58
80	24·00	21	5·05
120	11·20	23	2·58
200	8·55	25	2·14
- 200	17·25	28	4·83
Total	100·00		21·67

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	3·12
Tons - 200 grade produced in 24 hours.	2·54

Tube Mill Efficiency Test.

Date. Mar 11th 1912		Test Number. 15	
Dry Feed- 24 hours. 18 Tons.		Water in pulp. 38·2	%
R. P. M. 43		Pebble Load.	Lbs.
Mechanical value of Discharge		21·43	E.U.
Mechanical value of Feed.		19·09	E.U.
Work done per unit.		2·34	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		5·85	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		7·21	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.					Discharge.			
Grade.	%	E.U.	M.V.		Grade.	%	E.U.	M.V.
+ 20	15·45	15	2·32		+ 20	3·05	15	·46
30	24·40	17	4·15		30	11·65	17	1·98
50	26·15	19	4·97		50	25·00	19	4·75
80	19·55	21	4·10		80	25·60	21	5·37
120	7·46	23	1·72		120	11·51	23	2·65
200	4·28	25	1·07		200	7·80	25	1·95
- 200	2·71	28	·76		- 200	15·39	28	4·27
Total	100·00		19·09		Total	100·00		21·43

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	2·92
Tons - 200 grade produced in 24 hours.	2·28

Tube Mill Efficiency Test.

Date. Mar 18th 1912	Test Number: 16		
Dry Feed- 24 hours. 18 Tons.	Water in pulp:	40.5	%
R. P. M. 43	Pebble Load:	1050	Lbs.
Mechanical value of Discharge		21.90	E.U.
Mechanical value of Feed.		19.34	E.U.
Work done per unit.		2.56	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		5.69	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		8.12	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.					Discharge.			
Grade.	%	E.U.	M.V.		Grade.	%	E.U.	M.V.
+ 20	12.45	15	1.86		+ 20	2.84	15	.42
30	23.67	17	4.02		30	11.12	17	1.89
50	26.63	19	5.06		50	22.15	19	4.20
80	20.64	21	4.34		80	23.75	21	4.99
120	8.85	23	2.04		120	11.46	23	2.63
200	4.92	25	1.23		200	8.18	25	2.04
- 200	2.84	28	.79		- 200	20.50	28	5.73
Total	100.00		19.34		Total	100.00		21.90

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	3.76
Tons - 200 grade produced in 24 hours.	3.18

Tube Mill Efficiency Test.

Date. Mar 20th 1912	Test Number. 17		
Dry Feed- 24 hours. 18 Tons.	Water in pulp. 33.2		%
R. P. M. 34	Pebble Load.		Lbs.
Mechanical value of Discharge		19.58	E.U.
Mechanical value of Feed.		16.70	E.U.
Work done per unit.		2.88	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		4.17	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		12.45	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.			
Grade.	%	E.U.	M.V.
+ 20	44.40	13	5.76
30	18.50	17	3.15
50	15.85	19	3.01
80	11.85	21	2.49
120	4.90	23	1.13
200	2.74	25	.68
- 200	1.76	28	.48
Total	100.00		16.70

Discharge.			
Grade.	%	E.U.	M.V.
+ 20	19.95	14	2.80
30	20.35	17	3.47
50	20.55	19	3.94
80	15.55	21	3.27
120	7.20	23	1.66
200	4.90	25	1.22
- 200	11.50	28	3.22
Total	100.00		19.58

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	2.15
Tons - 200 grade produced in 24 hours.	1.76

Tube Mill Efficiency Test.

Date. Mar 20th 1912		Test Number. 18	
Dry Feed- 24 hours. 18 Tons.		Water in pulp. 36.7	%
R. P. M. 34		Pebble Load. 1050	Lbs.
Mechanical value of Discharge		19.76	E.U.
Mechanical value of Feed.		16.70	E.U.
Work done per unit.		3.06	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		4.39	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		12.55	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.			
Grade.	%	E.U.	M.V.
+ 20	44.40	13	5.76
30	18.50	17	3.15
50	15.85	19	3.01
80	11.85	21	2.49
120	4.90	23	1.13
200	2.74	25	.68
- 200	1.76	28	.48
Total	100.00		16.70

Discharge.			
Grade.	%	E.U.	M.V.
+ 20	16.35	14	2.29
30	20.25	17	3.44
50	22.15	19	4.20
80	16.90	21	3.55
120	7.40	23	1.70
200	5.30	25	1.32
- 200	11.65	28	3.26
Total	100.00		19.76

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	2.24
Tons - 200 grade produced in 24 hours.	1.78

Tube Mill Efficiency Test.

Date. Mar 20th 1912		Test Number.	19	
Dry Feed- 24 hours. 18 Tons.		Water in pulp.	38.0	%
R. P. M. 34.0		Pebble Load.		Lbs.
Mechanical value of Discharge			19.74	E.U.
Mechanical value of Feed.			16.70	E.U.
Work done per unit.			3.04	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.			4.27	H.P.
Deduct Mill Friction			—	H.P.
Nett Power - Raising pebbles and pulp			—	H.P.
Relative Mechanical Efficiency based on Gross Power.			12.80	
Relative Mechanical Efficiency based on Nett Power.			—	

Screen Analyses.

Discharge. ~~Feed.~~

Grade.	%	E.U.	M.V.
+ 20	17.80	14	2.49
30	19.95	17	3.39
50	20.95	19	3.98
80	16.30	21	3.42
120	7.60	23	1.75
200	5.40	25	1.35
- 200	12.00	28	3.36
Total	100.00		19.74

Feed. ~~Discharge.~~

Grade.	%	E.U.	M.V.
+ 20	44.40	13	5.76
30	18.50	17	3.15
50	15.85	19	3.01
80	11.85	21	2.49
120	4.90	23	1.13
200	2.74	25	.68
- 200	1.76	28	.48
Total	100.00		16.70

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	2.32
Tons - 200 grade produced in 24 hours.	1.84

Tube Mill Efficiency Test.

Date. Mar 25th 1912.	Test Number. 20		
Dry Feed- 24 hours. 18 Tons.	Water in pulp.	40·5	%
R. P. M. 34	Pebble Load.	1060	Lbs.
Mechanical value of Discharge		20·15	E.U.
Mechanical value of Feed.		16·75	E.U.
Work done per unit.		3·40	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		4·47	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		13·65	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.			
Grade.	%	E.U.	M.V.
+ 20	44·88	13	5·82
30	17·61	17	3·00
50	15·54	19	2·95
80	11·94	21	2·51
120	4·90	23	1·13
200	3·12	25	·78
- 200	2·01	28	.56
Total	100·00		16·75

Discharge.			
Grade.	%	E.U.	M.V.
+ 20	13·30	14	1·86
30	19·20	17	3·27
50	22·50	19	4·27
80	18·10	21	3·80
120	8·20	23	1·89
200	5·95	25	1·49
- 200	12·75	28	3·57
Total	100·00		20·15

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	2·44
Tons - 200 grade produced in 24 hours.	1·93.

Tube Mill Efficiency Test.

Date. March 25th 1912.		Test Number. 21	
Dry Feed- 24 hours. 18 Tons.		Water in pulp. 38·0	%
R. P. M. 38		Pebble Load. 1050	Lbs.
Mechanical value of Discharge		20·23	E.U.
Mechanical value of Feed.		16·75	E.U.
Work done per unit.		3·48	E.U.
Gross power – Mill Friction plus Pebbles plus Pulp.		4·01(?)	H.P.
Deduct Mill Friction		——	H.P.
Nett Power – Raising pebbles and pulp		——	H.P.
Relative Mechanical Efficiency based on Gross Power.		15·59(?)	
Relative Mechanical Efficiency based on Nett Power.		——	

Screen Analyses.

Feed.				Discharge.			
Grade.	%	E.U.	M.V.	Grade.	%	E.U.	M.V.
+ 20	44·88	13	5·82	+ 20	13·30	15	2·00
30	17·61	17	3·00	30	18·85	17	3·16
50	15·54	19	2·95	50	23·05	19	4·38
80	11·94	21	2·51	80	17·90	21	3·76
120	4·90	23	1·13	120	8·20	23	1·89
200	3·12	25	·78	200	5·75	25	1·44
– 200	2·01	28	·56	– 200	12·85	28	3·60
Total	100·00		16·75	Total	100·00		20·23

Crushing Efficiency.

Tons – 120 grade produced in 24 hours.	2·43
Tons – 200 grade produced in 24 hours.	1·95

Tube Mill Efficiency Test.

Date. *Mar 25th 1912.*	Test Number. *22*		
Dry Feed- 24 hours. *18* Tons.	Water in pulp.	*38.0*	%
R. P. M. *30.6*	Pebble Load.	*1050*	Lbs.
Mechanical value of Discharge		*19.69*	E.U.
Mechanical value of Feed.		*16.75*	E.U.
Work done per unit.		*2.94*	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		*3.48*	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		*15.20*	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.

Grade.	%	E.U.	M.V.
+ 20	*44.88*	*13*	*5.82*
30	*17.61*	17	*3.00*
50	*15.54*	19	*2.95*
80	*11.94*	21	*2.51*
120	*4.90*	23	*1.13*
200	*3.12*	25	*.78*
- 200	*2.01*	28	*.56*
Total	*100.00*		*16.75*

Discharge.

Grade.	%	E.U.	M.V.
+ 20	*17.45*	*14*	*2.44*
30	*19.75*	17	*3.36*
50	*21.80*	19	*4.14*
80	*16.90*	21	*3.55*
120	*7.80*	23	*1.80*
200	*5.45*	25	*1.36*
- 200	*10.85*	28	*3.04*
Total	*100.00*		*19.69*

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	*2.01*
Tons - 200 grade produced in 24 hours.	*1.59*

Tube Mill Efficiency Test.

Date. Apr 2nd 1912.		Test Number. 23	
Dry Feed- 24 hours. 18 Tons.		Water in pulp. 38.0	%
R. P. M. 43		Pebble Load. 1050	Lbs.
Mechanical value of Discharge		21.93	E.U.
Mechanical value of Feed.		19.89	E.U.
Work done per unit.		2.04	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		4.84	H.P.
Deduct Mill Friction		——	H.P.
Nett Power - Raising pebbles and pulp		——	H.P.
Relative Mechanical Efficiency based on Gross Power.		7.60	
Relative Mechanical Efficiency based on Nett Power.		——	

Screen Analyses.

Feed.			
Grade.	%	E.U.	M.V.
+ 20	10.00	15	1.50
30	18.10	17	3.08
50	26.15	19	4.92
80	23.25	21	4.88
120	11.30	23	2.60
200	7.30	25	1.82
- 200	3.90	28	1.09
Total	100.00		19.89

Discharge.			
Grade.	%	E.U.	M.V.
+ 20	2.00	15	.30
30	8.20	17	1.40
50	23.55	19	4.47
80	26.60	21	5.59
120	13.10	23	3.02
200	9.70	25	2.42
- 200	16.85	28	4.73
Total	100.00		21.93

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	2.76
Tons - 200 grade produced in 24 hours.	2.33.

Tube Mill Efficiency Test.

Date. Apr 2nd 1912	Test Number. 24		
Dry Feed- 24 hours. 16·8 Tons.	Water in pulp. 39·6		%
R. P. M. 43	Pebble Load. 1050		Lbs.
Mechanical value of Discharge		22·65	E.U.
Mechanical value of Feed.		20·92	E.U.
Work done per unit.		1·73	E.U.
Gross power - Mill Friction plus Pebbles plus Pulp.		5·35	H.P.
Deduct Mill Friction		—	H.P.
Nett Power - Raising pebbles and pulp		—	H.P.
Relative Mechanical Efficiency based on Gross Power.		5·43	
Relative Mechanical Efficiency based on Nett Power.		—	

Screen Analyses.

Feed.			
Grade.	%	E.U.	M.V.
+ 20	—	—	—
30	6·60	17	1·12
50	37·35	19	7·10
80	30·15	21	6·34
120	12·90	23	2·96
200	8·15	25	2·04
- 200	4·85	28	1·36
Total	100·00		20·92

Discharge.			
Grade.	%	E.U.	M.V.
+ 20	—	—	—
30	2·00	17	·34
50	20·80	19	3·95
80	30·70	21	6·45
120	15·70	23	3·61
200	11·80	25	2·95
- 200	19·10	28	5·35
Total	100·00		22·65

Crushing Efficiency.

Tons - 120 grade produced in 24 hours.	3·01
Tons - 200 grade produced in 24 hours.	2·40.

SUMMARY.

Test No.	Character of Feed.	M.V. of Feed.	Feed Tons per 24 hrs.	% Moisture	R.P.M.	Pebble Load.	H.P.	Work Done per UNIT.	Net Output -120 Tons 24 hrs.	R.M.E. PER H.P.	SERIES IN WHICH DATA ARE USED.
1	10 MESH	17.26	15.91	37.9	40	lbs 1050	5.19	3.62	2.78	11.10	No. I
2	" "	"	18.0	37.7	40	"	5.36	3.56	2.94	11.91	I, III
3	" "	"	20.0	37.9	40	"	5.47	3.35	3.09	12.25	I
4	" "	17.14	18.0	38.4	43	"	5.77	3.50	2.80	10.90	II, III, IV
5	" "	17.26	"	37.3	"	"	5.50	3.67	2.91	12.00	II
6	" "	"	"	36.9	"	"	5.37	3.68	2.93	12.31	II
7	" "	17.14	"	35.4	"	"	5.35	3.81	3.16	12.80	II
8	" "	"	"	33.8	"	"	5.04	4.03	3.38	14.40	II
9	" "	"	"	32.2	"	"	5.57	3.90	3.50	12.60	II
10	" "	16.61	"	32.3	"	"	5.75	4.18	3.30	13.06	II
11	" "	17.14	"	30.6	"	"	5.40	4.20	4.07	13.97	II
12	18 "	19.27	"	34.2	"	"	5.67	2.40	3.16	7.62	II
13	" "	19.34	"	36.2	"	"	5.65	2.47	3.39	7.85	II
14	" "	19.24	"	38.0	"	"	5.18	2.43	3.12	8.45	II, IV
15	" "	19.09	"	38.2	"	"	5.85	2.34	2.92	7.21	II
16	" "	19.34	"	40.5	"	"	5.67	2.56	3.76	8.12	II
17	10 "	16.70	"	33.2	33.6	"	4.17	2.88	2.15	12.45	II
18	" "	"	"	36.7	34.0	"	4.39	3.06	2.24	12.55	II
19	" "	"	"	38.0	34.0	"	4.27	3.04	2.32	12.80	III, II
20	" "	16.75	"	40.5	34.0	"	4.47	3.40	2.44	13.65	II
21	" "	"	"	38.0	38.0	"	4.01	3.48	2.42	15.59	III
22	" "	"	"	"	30.6	"	3.48	2.94	2.01	15.20	III
23	Classified Discharge	19.89	"	"	43.0	"	4.84	2.04	2.76	7.60	IV
24	30 MESH.	20.92	16.8	39.6	43.0	"	5.35	1.73	3.01	5.43	IV.