Hardinge Mills vs. Chilean Mills.

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In view of the prominence which the conical mill has attained in the fine-crushing field within the few years since its introduction, the following comparison with its more mature forerunner, the Chilean mill, based on extensive tests, is submitted in the interest of the milling profession.

Soon after designing the concentrating plant of the Miami Copper Co. in 1909, the Hardinge conical mill made its appearance in the milling forum. Its possibility as a suitable crushing device for the plant was well recognized, but in view of the lack of commercial demonstration, at the time, as to capacity, efficiency for desired product, and the still more uncertain factors of cost of maintenance and power consumption, it was deemed that the immediate adoption of this machine throughout the plant would be a hazardous undertaking. For these reasons it was decided to equip the majority of the immediately required units of the plant with Chilean mills, the fine-crushing proficiencies of which were better known, and one section with Hardinge mills, to serve as a test unit for the guidance of future installations and replacements. Thereby, after 1.5 years' operation with both types of mills, a thorough test as to metallurgical efficiency and cost economy has been obtained.

The conical mill used in these tests is the 8-ft. Hardinge pebble mill, having a cylinder 22 in. in length. The cylindrical portion of this mill is lined with cast-iron liner plates, and the conical extensions with silex bricks bound together by cement. Each liner plate carries a projecting lifter, the function of which is to increase the height of drop of the lifted material. Danish No. 5 pebbles, obtained from the coast deposits of Denmark, are used for the grinding charge. The Chilean mill used is a fast-running, 3-roller, 6-ft. Saturn mill, with screens of 0.037-in. opening. The feed to these mills is the oversize of Callow screens having 0.029-in. openings, which follow rolls crushing to 0.5 in.

For the ore of this mine, a moderately hard but very fissile schist, impregnated with finely disseminated granular chalcocite, the conical mill has proved itself superior, metallurgically and economically, as a fine-grinding machine. This superiority it has attained by a combination of commendable characteristics, namely: Smoothness and steadiness of operation, delivery of a product enabling better extraction, more economical water consumption, a lower operating and maintenance cost, and a very low rate of depreciation.

Steadiness in operation, of paramount importance in plants of such large capacities, is effected in this type of mill by its simplicity in principle and the consequent simplicity in construction. Discharge screens, dies, and mullers are eliminated, and in their place more desirable crushing equivalents are substituted. Thus, the screen of the Chilean mill is replaced by a perpetual device; the dies by linings which have long life; and the mullers by flint pebbles which are replaceable without interruption to operation.

Delays with these two types of mills in this plant have been found to be as follows:

Chilean Mills.	Per Cent.	*Hardinge Mills.*	Per Cent.
Screen delays,	0.57	Relining delays,	0.71
Repair delays,	1.54	Repair delays,	0.58
Total delay,	2.11	Total delay,	1.29

From the above it is seen that the delays of the Hardinge mill approximate 60 per cent. of those of the Chilean mill, and that relining constitutes more than one-half of the total delay. This is mainly due to the fact that when a mill is relined it must be idle about 48 hours, so as to give the cement used for binding time to set. This delay, however, can be materially reduced by means of shell stands, so that a newly relined shell will always be ready to be replaced by an overhead crane when a worn-out shell is to be removed. Allowing 2 hours for this replacement, the delay from this cause will be reduced to about 0.05 per cent. Thus the necessary delays with this mill simmer down to those of repairs to bearings and pinions, lifting out a shell with worn lining and reinstating a renewed one, and the occasional replacement of feed scoops, which approximate a total delay of about 0.6 per cent.

Less actual attendance is required by the Hardinge mill. This makes it possible to reduce the operating cost in plants where the duty of the attendant can be so distributed as to include the supervision of other apparatus. Occasional pebble feed, lubrication, and a look-out for obstructed discharge boxes, are the only services required. By their adoption in this plant the operating labor cost of fine crushing has been reduced about one-half.

For the reduction practiced at this plant, the conical mill has proved itself to be the more suitable fine-grinding machine. Because of the generally granular character of the chalcocite of this ore, it is the aim to produce a product of such size as will liberate a maximum mineral content with as small a production of ultra fines as possible. It has been found that a product which contains a maximum percentage between the sizes of 60 and 200 mesh is best. Below is given a typical screen analysis of feed and product for both types of mills. From this it is seen that the Hardinge mill yields 37 per cent. of the desired size of material or about 50 per cent. more than the Chilean mill, and with a smaller production of slime.

Mesh.	Chilean Mill.		Hardinge Mill.	
	Feed.	Product.	Feed.	Product.
+ 4	13.9	0	12.9	0
+ 10	47.5	0	47.3	0
+ 20	22.9	2.3	26.8	0.2
+ 30	5.2	11.8	5.0	3.2
+ 40	0.9	6.7	0.8	4.9
+ 60	1.0	11.4	0.8	13.8
+ 80	0.5	6.7	0.4	10.4
+ 100	0.4	5.4	0.3	8 6
+ 150	0.5	6.3	0.3	8.0
+ 200	0.7	7.2	0.5	10.0
— 200 sand	1.2	10.6	0.8	10.0
— 200 slime	5.3	31.6	4.1	30.9

The Hardinge mill also consumes less power. At this plant, a 150-h-p. induction motor operates three 8-ft. Hardinge mills or two 6-ft. Chilean mills, and the power consumption, for the above reduction, is as given below. The consumption is given on the basis of both crude-ore tonnage and actual feed tonnage, the latter being approximated at 70 per cent. of the former.

	Crude-Ore Tonnage.	Actual Feed Tonnage.
	Horse-Power-Hr. Per Ton.	Horse-Power-Hr. Per Ton.
Chilean mill, ...	7.5	10.7
Hardinge mill, ...	6.7	9.6

A striking feature brought out by the comparative operation of these mills, is the difference in the duty exacted of the cone tanks. The sections of the plant operated with Hardinge mills have shown an average reduction of nearly 75 per cent. in the solid feed and a 40 per cent. reduction in the water feed to these tanks, as compared with the Chilean mill. This is to be attributed to the combined result of the smaller quantity of water fed to the grinding mill and of the smaller production of slimes. For plants where the production of extreme fines is not desired, the opportunity is thereby offered of lessened outlay for dewatering equipment.

The maintenance costs of Chilean and Hardinge mills are shown in the accompanying tables. The cost for each mill is based on crude-ore tonnage so that the cost per ton of actual feed would be 40 per cent. greater than the cost shown, as in the reduction practice of this plant about 70 per cent. of the crude-ore tonnage passes through the fine-grinding mills.

Chilean Mill.

Tons milled, 826,000.

Driving Mechanism.	Cost Per Ton.	
Shafts, pinions and gears,	$0.00230	
Spindles, muller bushings, etc.,	0.00275	
Miscellaneous,	0.00042	
		$0.00547
Crushing Mechanism.		
Dies (12,910 tons per die),	$0.01079	
Tires (7,310 tons per tire),	0.00987	
Screens (183 tons per screen),	0.00893	
Miscellaneous,	0.00176	$0.03135
Total supplies,		$0.03682
Repair labor,		0.00841
Shop expense,		0.00543
Total maintenance cost,		$0.05066

Hardinge Mill.

Tons milled, 450,000.

	Cost Per Ton.	
Shafts, pinions and gears,		$0.00036
Lining.		
Liner plates and lifters,	$0.00403	
Silex,	0.00300	
Cement,	0.00050	
		0.00753
Pebbles (2.51 lb. @ $0.013),		0.03262
Miscellaneous,		0.00012
Total supplies,		$0.04063
Repair labor,		0.00268
Shop expense,		0.00214
Total maintenance cost,		$0.04545

From this it is seen that the Hardinge mill, for the practice of this plant, shows a maintenance cost of about 0.5 c. per ton less than the Chilean mill. It is to be noted, however, that pebble consumption constitutes 70 per cent. of this cost, and the freight on pebbles comprises approximately 50 per cent. of their expense in this locality. The item of "shafts, gears and pinions" is probably somewhat low, in that these mills have not been operated sufficiently long to obtain a true average. Nevertheless, this part of the cost is small since these gears have a long life, and, constituting but a small percentage of the total, is inconsequential.

However, the decisive factor of the lower cost of the Hardinge mill is its low rate of depreciation. The life of its shell, if proper care is taken that the lining is not allowed to wear through to it, is very long. Six Chilean mills have shown an efficient life of 825,000 tons, making the rate of depreciation, inclusive of transportation and installation costs, about 3 c. per ton. Allowing a life of 10 years for the Hardinge mill, its depreciation cost would be less than 0.5 c. per ton.

Summarizing these factors, the net gain in cost by operating with the Hardinge mill, for the practice of this plant, shows as follows:

Operating.	Cost Per Ton. Cents.
Labor,	0.50
Power—0.6 kw-hr.,	0.75
	1.25
Maintenance,	0.50
Depreciation,	2.50
Saving,	4.25

To the above are to be added other advantages, the more conspicuous of which are: greater capacity by reason of lower power consumption and lower delays; superior product enabling a better extraction to be made; smaller water consumption; and for minimum slime practice requires less dewatering equipment.

Furthermore, this mill is not yet out of the experimental stage, and there are possibilities of still better performances. For instance, by lengthening the cylinder of a 6-ft. middlings recrushing mill from 22 to 38 in., it was found that the capacity of the mill was doubled, the power consumption lessened, and the pebble cost decreased to nearly one-half. It would seem, however, that this idea can be carried too far, for the more the cylinder of this mill is lengthened, the more it tends to approach a tube mill, and so become a slimer. For regrinding middlings, however, this variation in dimension is a step in the right direction, in that the liberation of occluded mineral necessitates a fine product. Also large percentage variation in the sizes of feed seems to have a considerable influence on the consumption of pebbles. Thus it was found in a test in which all the feed was sized through 2.5 mm., that the pebble consumption was 1.85 lb. per ton of actual feed as against a consumption of 3.60 lb. with the oversize feed shown in the table. Experimental variations in speed, in dilution of the feed, and in size of pebble charge, may lead to further economies.

An interesting comparison, which, while based on rather ideal assumptions, is so decisive in result as to be given credit, is the mechanical crushing efficiency of these machines determined by the method of calculation discussed by Algernon del Mar in his article on Mechanical Efficiency of Crushing.[1] These calculations, as shown in the accompanying tables, are based on Rittinger's law that "the work done in crushing is proportional to the reduction in diameter." This assumes that all surfaces exposed give the same unit resistance to crushing, whereas it is to be inferred that there are some surfaces which, by reason of inherent fissility of the ore, offer a lower unit resistance than surfaces not so favored. However, in view of the large number of surfaces produced, it would seem reasonable to assume that an average unit resistance to crushing will prevail in a not unduly long test. Furthermore, since in these calculations both machines are treated equitably with regard to the practical variations which do not enter into the law, the comparative results can be considered fairly reliable.

Table I. shows the crushing efficiency without regard to quality of product made, from which it is seen that the units of reduction performed by the Hardinge mill exceed those of the Chilean mill by from 18 to 23 per cent., depending upon the degree of accuracy attained in the assumptions made in the calculations, and considering 5 per cent. as a safe limit. This evaluation proves that the Hardinge mill converts more of the power consumed into reduction of the charge than does the Chilean mill.

Table II. shows the comparative crushing efficiency with regard to size of product made. From this it is seen that in amount of work performed on the various sizes of the feed, the Hardinge mill exceeds the Chilean mill in all cases, again showing that this mill converts more of the power taken by it into actual work done. Furthermore, the excess work done is mostly expended on the grades of product desired, thereby proving that this mill more efficiently fulfills the duties assigned. It is here that the cone comes into play. This geometrical device serves the function of adjusting the crushing energy expended so as to be proportional to the force required to reduce the particles to a given size. This is effected by two principles that are inherent with the operation of the mill. First, through the continual displacement of the larger particles of the charge upon the smaller, there takes place a segregation of the particles in the cone according to size—the larger assuming positions at the greater diameter and the smaller receding toward the smaller end of the cone

[1] *Engineering and Mining Journal*, vol. xciv., No. 24, p. 1129 (Dec. 14, 1912).

of the mill; second, through the combined action of this segregation and the diminishing action of centrifugal force toward the apex of the cone, varying intensities of energy are imparted to the pebbles —the larger receiving greater inertia by reason of greater mass and greater lift and the smaller less and less inertia by reason of the smaller mass and lower lift. Thus there exist within the mill an orderly arrangement of zones of ore particles, each requiring a certain amount of impact to be reduced to a given size, and a series of zones of forces so arranged as to impart impacts that tend to be proportional to the crushing energy required by the ore particles upon which these forces are exerted. For these reasons the production of slimes is minimized and the accumulated forces are utilized to best advantage, whereas in the Chilean mill the crushing forces are uniform and disadvantageously expended upon a mixed aggregation of coarse and fine particles.

The Hardinge ball mill has also been tested in this plant as a substitute for rolls, for intermediate crushing on 0.5-in. material. This mill, however, was soon discarded, since it was found that the desired product could only be obtained at too low a capacity, and the consumption of steel balls was too great to be economical.

Thanks are due J. Parke Channing, Consulting Engineer and Vice-President of the Miami Copper Co., for permission to publish the above data. I am also indebted to B. Britton Gottsberger, General Manager, for his kindness in placing at my disposal the metallurgical data of these tests.

TABLE I.—*Mechanical Crushing Efficiency—Hardinge vs. Chilean Mills.*

On basis of law, that "the work done in crushing is proportional to the surface exposed in crushing" and therefore "nearly proportional to the reduction in diameter" or "nearly proportional to the reciprocals of the diameters crushed to."

Hardinge Mill.						Chilean Mill.					
Mesh.	Reciprocal of Average Size.	Feed. Per Cent.	Relative Surface in Feed.	Product. Per Cent.	Relative Surface in Product.	Mesh.	Reciprocal of Average Size.	Feed. Per Cent.	Relative Surface in Feed.	Product. Per Cent.	Relative Surface in Product.
+ 4	4.1	12.9	53	0	. . . .	+ 4	4.1	13.9	57	0	. . .
+10	7.2	47.3	341	0	. . . .	+ 10	7.2	47.5	342	0	. . .
+20	18.3	26.8	490	0.2	4	+ 20	18.3	22.9	419	2.3	42
+30	37.7	5.0	189	3.2	121	+ 30	37.7	5.2	196	11.8	445
+40	58.4	0.8	47	4.9	286	+ 40	58.4	0.9	53	6.7	391
+60	83.6	0.8	67	13.8	1,154	+ 60	83.6	1.0	84	11.4	953
+80	138	0.4	55	10.4	1,435	+ 80	138	0.5	69	6.7	925
+100	163	0.3	49	8.6	1,402	+100	163	0.4	65	5.4	880
+150	220	0.3	66	8.0	1,760	+150	220	0.5	110	6.3	1,386
+200	303	0.5	151	10.0	3,030	+200	303	0.7	212	7.2	2,182
—200	400	4.9	1,960	40.9	16,360	—200	400	6.5	2,600	42.2	16,880
		100.0	3,468	100.0	25,552			100.0	4,207	100.0	24,084

SUMMARY.

	Hardinge.	Chilean.
Units of work in product	25,552	24,084
Units of work in feed	3,468	4,207
Units of work done by mill uncorrected for capacity	22,084	19,877
Units at capacities of 2.50 tons and 2.25 tons per h-p. day, respectively	55,210	44,723

Excess units of work done by Hardinge mill 10,487

Excess efficiency, assuming method of calculation correct . . . . . . 23.45 per cent.

Excess efficiency, assuming 5 per cent. as the limit of error . . . . . 18.45 per cent.

TABLE II.—*Screen Size Crushing Efficiency.*

Hardinge Mill.

Mesh.	Reciprocal of Aperture.	Feed. (Cumulative Per Cent.)	Relative Surface in Feed.	Product. (Cumulative Per Cent.)	Relative Surface in Product.	Relative Surface Produced.
4	4.9	87.1	427	100.0	490	63
10	13.3	39.8	529	100.0	1,330	801
20	29.4	13.0	382	99.8	2,934	2,552
30	50.5	8.0	404	96.6	4,878	4,474
40	66.7	7.2	480	91.7	6,116	5,636
60	115	6.4	736	76.9	8,844	8,108
80	147	6.0	882	66.5	9,776	8,894
100	182	5.7	1,037	57.9	10,538	9,501
150	272.5	5.4	1,472	49.9	13,598	12,126
200	333	4.9	1,632	40.9	13,620	11,988

Chilean Mill.

Mesh.	Reciprocal of Aperture.	Feed. (Cumulative Per Cent.)	Relative Surface in Feed.	Product. (Cumulative Per Cent.)	Relative Surface in Product.	Relative Surface Produced.
4	4.9	86.1	422	100.0	490	68
10	13.3	38.6	513	100.0	1,330	817
20	29.4	15.7	462	97.7	2,872	2,410
30	50.5	10.5	530	85.9	4,338	3,808
40	66.7	9.6	640	79.2	5,283	4,643
60	115	8.6	989	67.8	7,797	6,808
80	147	8.1	1,191	61.1	8,982	7,791
100	182	7.7	1,401	55.7	10,137	8,736
150	272.5	7.2	1,962	49.4	13,462	11,500
200	333	6.5	2,165	42.2	14,053	11,888

Comparison of Efficiency.

With Units Corrected for Capacity.

Size.	Hardinge Mill.	Chilean Mill.	Difference in Favor of Hardinge.	Distribution.
	Energy Units.	Energy Units.		Per Cent.
At 4 mesh	158	153	5	0.02
At 10 mesh	2,002	1,838	164	0.57
At 20 mesh	6,380	5,423	957	3.32
At 30 mesh	11,185	8,568	2,617	9.08
At 40 mesh	14,090	10,447	3,643	12.64
At 60 mesh	20,270	15,318	4,952	17.18
At 80 mesh	22,235	17,530	4,705	16.32
At 100 mesh	23,752	19,636	4,116	14.28
At 150 mesh	30,315	25,875	4,440	15.41
At 200 mesh	29,970	26,748	3,222	11.18

Discussion.

Arthur O. Gates, Lafayette, Ind. (communication to the Secretary*):—In connection with the comparison of mechanical crushing efficiencies in Tables I and II of Mr. Franke's paper, I wish to suggest a somewhat simpler way of making this comparison, based upon what the writer has called the "crushing-surface diagram," as published by him in the *Engineering and Mining Journal* for May 24, 1913. Such a diagram, based on the data given in Table II, is submitted herewith, Fig. 1, cumulative percentages being plotted as abscissæ and recipro-

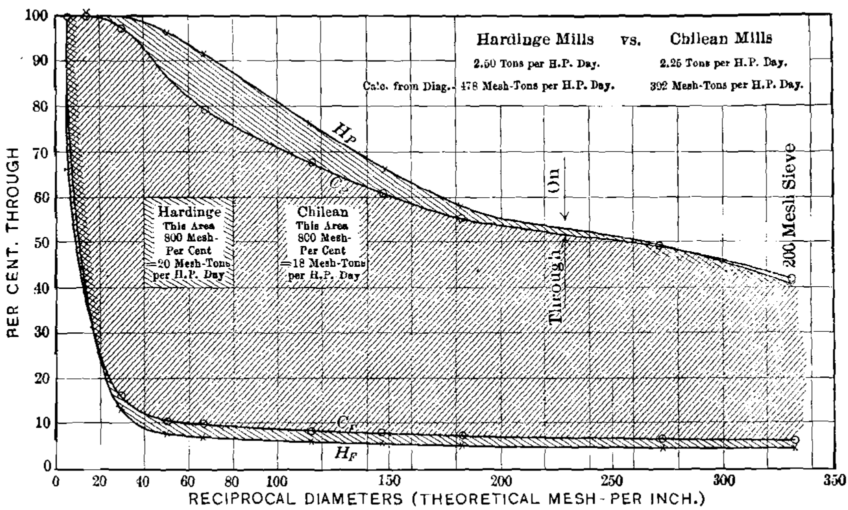

Fig. 1.—Crushing Efficiencies of Hardinge and Chilean Mills, Plotted on Crushing-Surface Diagram.

cals of diameters (theoretical mesh per inch) plotted as ordinates. Such a diagram averages the diameters without calculation, and areas upon it are proportional to surface produced, and, in accordance with Rittinger's law, to energy spent on crushing alone.

The Chilean mill diagram has been superimposed upon that of the Hardinge mill, the excess area of the latter measuring the excess of work done, based upon equal capacity. Measuring these areas up to 200 mesh (reciprocal 333), and multiplying by the tons per horse-power day, the writer gets a production of 392 mesh-tons per horse-power day for the Chilean mill, and 478 mesh-tons per horse-power day for the Hardinge, an increase of some 22 per cent. in favor of the

* Received Aug. 8, 1913.

Hardinge. (The term *mesh-ton* represents the increased surface produced by crushing all particles of a ton of rock to a diameter whose reciprocal is one greater than in its previous condition. Diameter should be in inches, although of course this can be adapted to other units. For example, a ton of evenly sized pieces 1 in. in diameter would have 1 mesh-ton of surface; a ton of similar pieces just passing a hole 0.01 in., and retained on a screen with holes the reciprocal of whose diameter was 101, would have 100 mesh-tons of surface; the difference between two lots of 1 ton each, whose diameter reciprocals were respectively 99 and 100, is 1 mesh-ton.)

While the 22 per cent. in favor of the Hardinge mill checks with Mr. Franke's results, I wish to question his adoption of the value 400 as the reciprocal of average size of the material passing the 200-mesh sieve. From the way the curve of products is running (in the plotted crushing-surface diagram) there is every indication that there is 1,000 and 10,000 reciprocal (theoretical mesh) material present, so of course the average size is very much smaller than he has indicated. The field beyond 200 mesh (ordinary screen) has been so little explored that it would seem advisable to limit calculations on efficiencies to the plus 200-mesh sizes.

If the results of Mr. Franke's sizing analysis in Table II are plotted on logarithmic paper instead of on the crushing-surface diagram, the last few points will be found in a straight line for both machines, with this difference: the Hardinge line is steeper than the Chilean line, as shown in Fig. 2. I have found similar straight lines as a result of plotting other results, indicating a law by means of which the minus 200-mesh material may be studied. It will be sufficient to state here that the straight line indicates a hyperbola for the screen analysis plotted reciprocals against weights or percentages as in the crushing-surface diagram, and further, that the steeper line on the logarithmic plotting indicates the more efficient work.

In spite of the commercial success of the Hardinge mill, and the increased economic results accomplished by its introduction into concentrating mills, I wish to criticize the statements that, as in this paper, are so frequently made as to the value of the cone, its segregating action on the pulp, and the graduation of forces, intensities of energy, or inertia so that each particle gets just the right blow. I have never seen any published results of screen analyses of material taken at different points along the cone, and I do not think screen analyses taken at these points will bear out the claims made for this feature.

Analyzing the mill on the assumption that the greatest diameter is to produce the greatest effect in crushing, we find that the weight of crushing pebbles is proportional to the square of the diameter (machine half full); that the energy per unit pebble weight is something nearer the square than the first power of the diameter; and that the velocity with which the ore or pulp being crushed passes through the mill is inversely proportional to the square of the diameter. The result

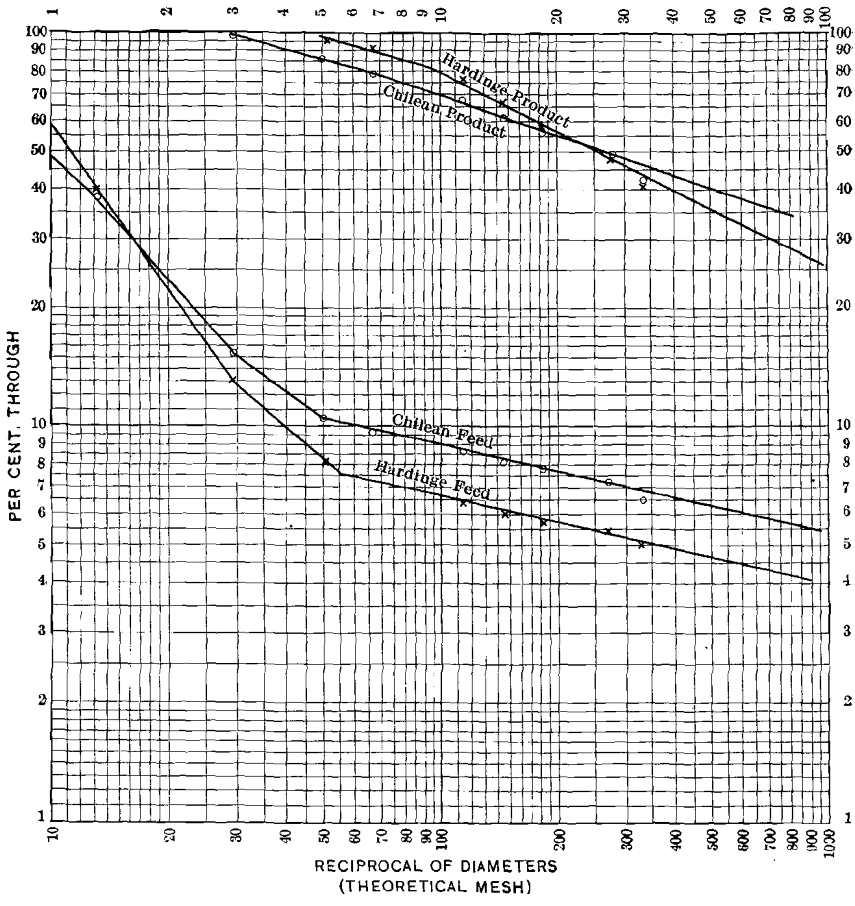

FIG. 2.—LOGARITHMIC PLOTTING OF CRUSHING EFFICIENCIES OF HARDINGE AND CHILEAN MILLS.

is that the energy applied per pound of pulp at various points along the cone is inversely proportional to about the sixth power of the diameter. This means that half way toward the apex of the cone, only 1/64 as much work is done as at the cylindrical portion, while three-fourths of the way toward the apex, only 1/4000 is done. This means that the energy applied along the cone is so small that the force exerted by the falling or rolling pebbles is not sufficient to break the coarser particles, with the result that the work in the cone is largely done on the fines! This is as logical as the generally accepted explanation.

But the Hardinge mill is not run at such speeds that the effect of the large diameter is obtained; it runs at such a speed (750 ft. per minute peripheral speed for the 8-ft. diameter size, according to Mr. Hardinge[1]) that centrifugal force at the periphery is about 1.2 times that of gravity and therefore at least one layer of pebbles in the

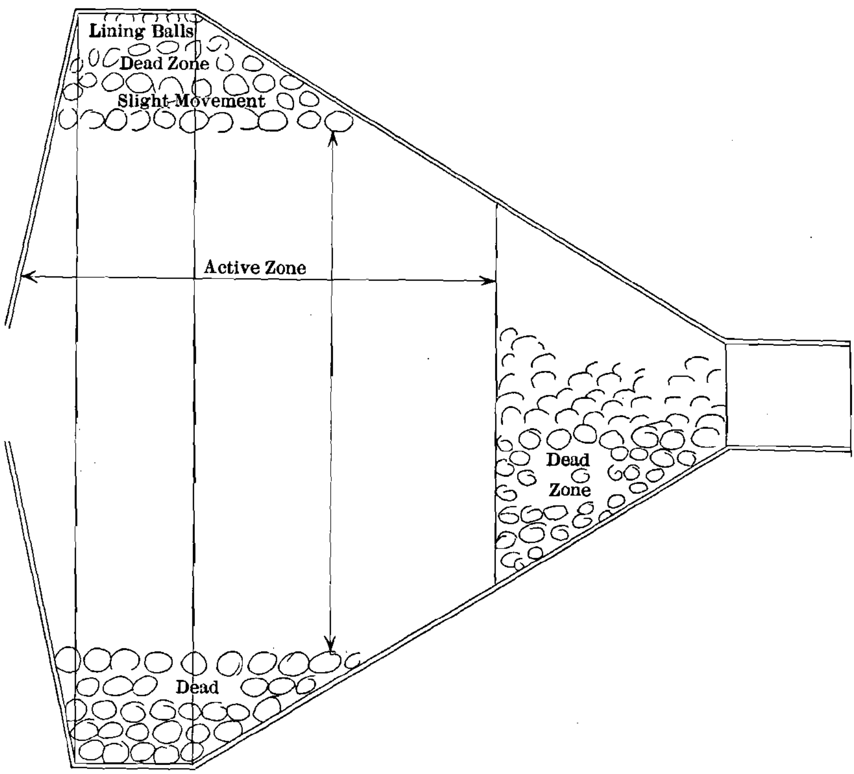

FIG. 3.—ACTIVE AND DEAD ZONES IN THE HARDINGE MILL.

periphery is useless except for the purposes of lining. For at least a foot in, the possible fall of the pebbles is so slight as to be valueless for crushing. The result is, neglecting part of the apex of the cone where the energy is too small to be effective, the Hardinge mill resolves itself automatically into a short tube mill, the 8-ft. size producing about the same effect as a 5 by 5 or 6 by 6 ft. tube mill, as in Fig. 3.

[1] *Trans.*, xlv., 201 (1913).

Perhaps I am like the sailor's mother who could credit his story about the mermaids, but refused to believe what he told her about the flying fish. The segregation of the pebbles is entirely reasonable, the survival of the most energetic, but how can the fines separate themselves from the coarse in the turmoil taking place within the crushing zone? The particle has got to go where it is knocked, the agitation is too great for it to follow any laws of classification, and it with the

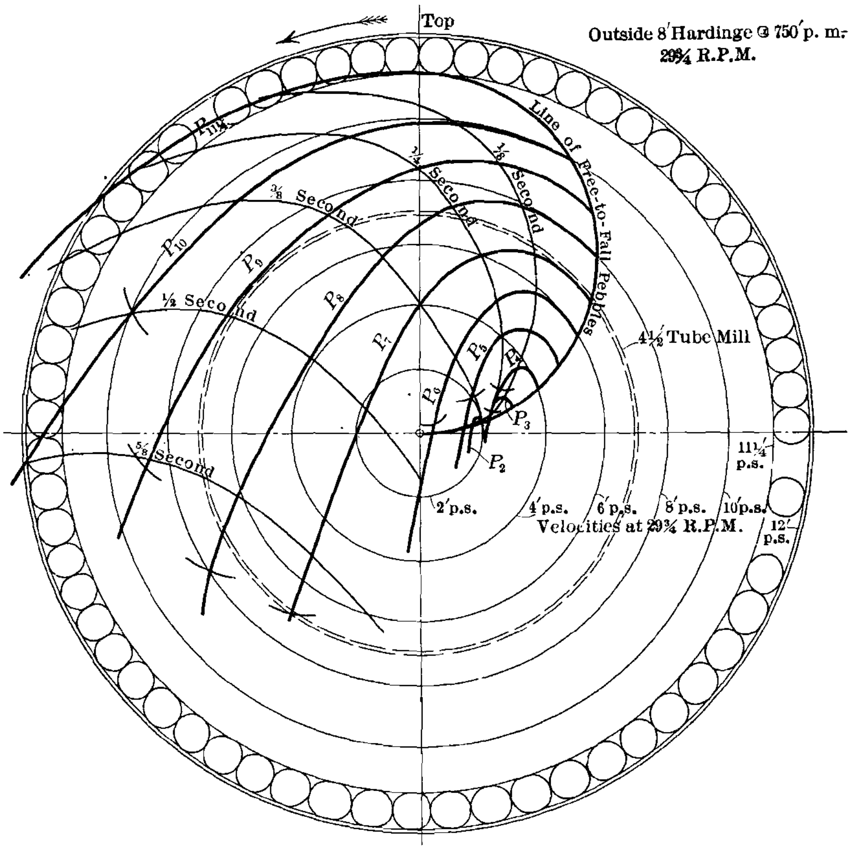

FIG. 4.—DIAGRAMMATIC REPRESENTATION OF THE ACTION IN A TUBE MILL.

others passes through by displacement and chance, perhaps getting through without being hit at all; or again, a single particle in the final pulp may be the result of perhaps a hundred blows.

In Figs. 4 and 5 are plotted some graphical results of calculation of what goes on inside a tube mill, particularly of the Hardinge type. The concentric circles in Fig. 4 represent planes through the cone. The velocity of each of these circles, based on 29.75 rev. per minute, is indicated in the lower right-hand quadrant. Applying the principles of mechanics, it will be found that pebbles will become free to fall when reaching the half-circle drawn in the upper right-hand quadrant, going up, and their paths from that time on will without interference follow the paths P_2, P_5, P_8, etc. Centrifugal force is too great on the outer ring of pebbles to let them move. Supposing pebbles to leave this half-circle along each of the concentric circles at the same time, lines of equal interval of time have been drawn so that one may judge velocities. I have not attempted to locate the landing place of

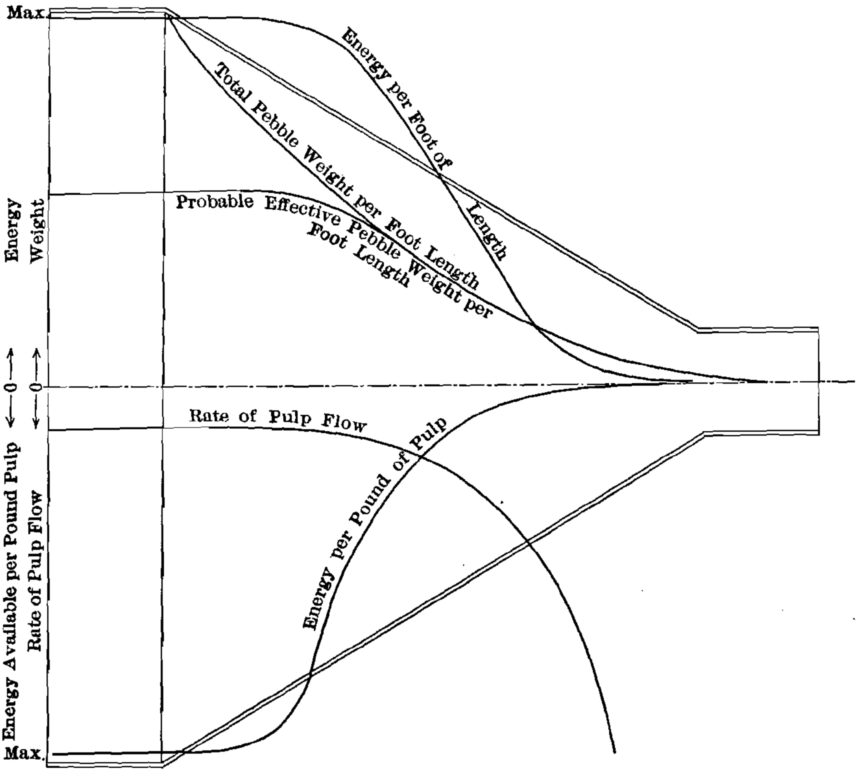

FIG. 5.—CURVES OF ENERGY, PEBBLE WEIGHT, AND FLOW OF PULP.

the pebbles very accurately, although I have shown possible landing places by curved lines across the path lines. When these landing places are located properly the resultant velocity can be determined graphically, energy then being proportional to the square of the velocity.

In Fig. 5 are plotted away from the horizontal axis of the mill, weights and energy available per foot of length, for different positions along the length of the mill, and below, the rate of flow of pulp through the mill, and the energy per pound of pulp imparted by the action of the pebbles. The curves are plotted to relative units, not absolute.

I predict that the fine-crushing machine of the future concentrating mill will be a short tube mill, followed by an efficient sizer to remove more of the fine material than is done at present, and followed by a second short tube mill. And by short tube mill I mean short, 1 or 2 ft. long, and perhaps of large diameter, the pulp traveling through it rapidly so that the fines are not subjected to repeated crushing.

The great advantage of the Hardinge mill is in its simplicity, reliability, and low operating charges, as Mr. Franke has so clearly shown, and most operators are interested most in these features. His comparison of efficiencies is one of the first real quantitative comparisons made in this country. It is my opinion that the day is coming when such comparisons of efficiency will be made from day to day in our milling plants, just as in the power plant indicator cards are taken and worked up at frequent intervals.