The Remarkable Case of the

Here's what happened:

Table 1. Improvements in Mill Performance Due to Decreased Ball Load

	NOW	BEFORE
Ball Load, tons	35	55
Ball Load, % volume	29%	45%
Tonnage	2250	2130
Horsepower Requirements	370	490
Ball Consumption, lb./ton	0.84	1.02
Grind: Sulphides—200 Mesh	65%	62%
Grind: Gangue—200 Mesh	35%	40%
Tails: Copper	0.068%	0.08%
Tails: Sulphur	2.5%	4.0%
Sod. Ethyl Xanthate, lb./ton	.28	.34

F. M. LEWIS
Mill Superintendent, at Tennessee Copper Co.'s Copperhill mills.

WHAT HAPPENED when the ball load in Tennessee Copper Co.'s huge Hardinge Tricone mill was reduced from 55 tons to 35 tons should give a lot of mill men food for thought. Not only did the reduced ball load make possible an increase in tonnage ground from 2130 to 2250, but power requirements dropped from 490 hp. to 370 hp. Nor was that all. As a result of the remarkable differential grind achieved (see table above), it has been possible to cut down on reagents.

Between August and October 1952 the amount of balls in the mill at Tennessee Copper's London plant was reduced from a load occupying 45% of the mill volume to a load occupying 29% of the mill volume. No other operating condition was changed. The mill turns over at 15 rpm (63% of critical speed), ball size is 1-in., average pulp density is 63% solids.

Results shown in Table I, were disclosed to a visiting *E&MJ* editor by Mr. F. M. Lewis, mill superintendent, who plans to experiment with further reduction in ball load in the near future. In addition to the lower ball consumption noted, it was possible to postpone an impending liner change because liner wear has been reduced.

Could the large classifying pool in this mill be contributing to these remarkable results? This pool has an area of about 70 sq. ft. and averages approximately 40-in. deep. The mill discharge is only 63% solids, but the material at the bottom of this pool, which must be the feed to the ball mass, is at least 75% solids. Also, this material is as clean as most conventional classifier sands. Thus only the coarse portion of the pulp in the mill, which has been thickened, ever enters the ball charge and in a very short time it is back in the mill pool for reclassifying.

Mr. Lewis doesn't know the answer at this time, but members of his staff are studying the conditions in their grinding circuit.

Copperhill Ball Mill

Here's what a few mill men think about it:

MILL MEN WE QUERIED about the facts on the opposite page were generally divided into two schools of thought. The first group seemed to agree that perhaps the classification taking place in the mill itself was responsible for the results achieved. Others were of the opinion that with the larger load of balls, power was being absorbed by balls contacting other balls with no particles interspersed; that is no grinding was being done by a goodly portion of the ball charge. With the reduced load more balls were effectively brought into play.

An eastern member of the milling fraternity, in discussing the situation by phone, felt that the key to the problem lay in the question; why couldn't the mill grind more ore with the initial large ball charge?

Another question that certainly needs an answer is; how far can you go in reducing the ball charge in the mill and receive further benefits?

Before we turn the floor over to some of the interesting specific replies, we'd like to invite your opinion and comment on the remarkable case of the ball mill at Copperhill.

BUNTING S. CROCKER
Mill Superintendent
Lake Shore Mines Ltd.

THE RESULTS SHOWN in Table I are so remarkable that one hesitates to offer any suggestions as to what has brought about this effect. The Tennessee Copper staff are to be congratulated on having enough pioneer spirit to go ahead and try the experiments shown because, regardless of the explanation, they apparently are making a substantial overall saving in their operation at the present load and speed.

In reviewing Professor H. E. T. Haultain's (University of Toronto) pictures of various ball loads and mill speeds, I remember that it took less per cent critical speed to give the usual ball action with 20% loads than with 60% loads. (E. W. Davis also pointed this out.) Thus, in this test the original mill with 45% volume at 63% critical speed

B. S. CROCKER
Different ball loads have different critical speeds.

may not have been producing as suitable a cascading action (or ball path action) as the present mill with 29% volume and the same speed. Certainly the grind is more efficient as shown by the figures but from a grinding point of view, not quite as efficient as the tonnage and power shown, as it will be noted that the gangue grind (which is probably 60% of the mill feed) is coarser on the 200 mesh under the present set up. The sulphides, of course, are being preferentially ground and are finer so they are doing the right thing metallurgically. However, I would not have expected ball action to have made as much difference as is listed in this test.

At Lake Shore, under reduced tonnage, on a mill running at 81% of critical speed we recently cut the ball load with a resulting drop in horsepower but a falling off in grind and the overall efficiency of the mill was slightly less than before. It may be that the phenomenon recorded at Tennessee is common to slow speed mills only.

HARLOW HARDINGE
President
Hardinge Co.

I MADE SEVERAL observations as to the reasons why the improvement occurred in this mill as reported.

Decreasing the ball load increases the number of ball cycles per revolution. For example, ignoring the time of fall, just consider operating with a mill at 50% ball load; those balls on the outer rim make two cycles per mill revolution. A mill at 25% ball loading would cause the same balls in the same location to drop four times per revolution. It is noted that this mill is operating with a relatively dilute pulp. "Doc" Lewis also observed that the pulp density in the mill pool was considerably higher near the bottom of the pool than at the top, or near the surface. A decreased ball load will cause the ball charge to operate in a higher pulp density and on the coarser size fractions, which will cause more effective grinding and as the ball-to-ball contact is reduced due to granular particles coming in between the balls, ball consumption would also be reduced. Since the grind has remained practically the same but at a very considerable reduction in power, it also follows that the power could well have been consumed by ball-to-ball contact which would increase ball wear. The fact that the ball consumption has been greatly reduced would tend to bear out this line of reasoning.

Effect of Specific Gravity

It is well to bear in mind that this ore has a gravity of 4.2. The apparent gravity of this ore in the water would then be 3.2 as against a gravity of 1.7 of a 2.7 specific gravity ore. The settling rate, therefore, of this ore in a dilute pulp averaging 63% solids as against the 75% to 85% solids in most of the mill operations would cause the classifying action that apparently occurs inside this mill.

When the mill was first operated, as has been reported by the progress reports at Tennessee Copper, it was found that a high density pulp did not work out nearly as well as when the density was considerably reduced. Now, further reduction in ball load has improved the operation. This is counter to many other cases where a very high ball load has improved results. But, in those cases, the pulp density was

HARLOW HARDINGE
Don't forget the effect of slower speeds in high level pulp mills.

E. H. CRABTREE
Where did the additional copper come from?

J. F. MYERS
A mill 100 ft. in diameter would not grind eggs.

much higher; the specific gravity of the ore, on the average, was lower; and the average ball size was greater. Apparently, the pulp density was so high as to preclude the possibility of any classifying action occurring within the mill pool. The latest findings at Tennessee Copper by F. M. Lewis certainly should be of interest elsewhere, but in evaluating these interesting results, it is important that many factors be considered. Only some have been commented upon here. It is also important to note that this is a high pulp level type of mill run at lower than standard speeds, which makes possible the formation of a pool under the conditions existing here.

E. H. CRABTREE
Director of Milling
Eagle Picher Co.

ANY TIME A MILL MAN can simultaneously reduce costs and improve recovery, he is really doing something; usually one of these is done at the expense of the other. It appears that "Doc" Lewis is following well in the footsteps of his eminent predecessor, Jack Myers.

Few mills have the facilities to control conditions as carefully as does Tennessee. Those who can should certainly attempt to duplicate these results. It is apparent that, from a finer sulphide grind and a coarser gangue grind, more copper was floated with fewer reagents. But, at the same time, considerably more iron was floated, evidently resulting in a lower grade rougher concentrate. It would be interesting to know if this resulted in a lower grade final concentrate. In other words, was the additional copper recovered freed by the finer sulphide grind, or was it recovered by floating more copper-iron middlings?

JACK MYERS
Consulting Engineer

IF YOU WILL REFER to the "Progress Report on Grinding at Tennessee Copper Co.," AIME. Vol. 187, June 1950, page 707, you will note that in Table III, Col. 6 (authors Myers and Lewis) when treating 2,100 tons per day, 412 hp. input was recorded and that the minus 200 mesh sulphide grind was 73%. This is a considerably finer grind than the 65% and 62% reported by Mr. Lewis in Table I.

It must be remembered also that this mill is operating with 1-in. forged steel balls and that the feed to the ball mill comes from a controlling rod mill that produces a product all through 14 mesh.

It is unfortunate that all the screen analysis figures are not given. I rather suspect that the power used to produce the 73% minus 200 mesh sulphide, as reported in Col. 6, is very close to the power consumed with the low ball load figure of 65%, maybe better.

There is another point that shall be mentioned. The figures in Col. 6, previously reported, were made when the mill liners were quite new and plenty of lift was present. In the two columns given in your Table I, the liners were practically worn out. In fact, they were removed just a few days prior to a visit I made at Copperhill in early April. An examination of these worn liners shows that the characteristic grooves, generated in the liners caused by ball slippage or rolling are present. This always occurs after lifter effect is worn off.

It will be remembered that Wright Hargreaves and Lake Shore found that this grooving is beneficial in transferring effective power from the mill shell to the ball charge and that prior to their present "rock" grinding process, they installed liners with grooves cast in them. If I remember correctly, they found that grooved liners were more advantageous than lifters when using balls 1¼ in. or less. The T. C. mill uses 1-in. balls so it would seem to me that this fact should be considered in analyzing the T. C. results. Mr. Lewis now has new liners in the mill and will, of course, be able to report on this point at a later date. I do wonder if Mr. Lewis took into consideration the fact that at a given ball loading, a mill with old liners carries more ball weight than one with new liners. The data in your questionnaire do not make this point clear. I cannot check the 35 tons of balls reported in Col. 1 of Table I.

However, none of the above comments detracts from the value of Mr. Lewis' observation and we are indeed indebted to him for reporting his results and to the editors of *Engineering and Mining Journal* for bringing it to the industry's attention. It certainly is an interesting fact that the ball consumption dropped from 1.02 to .84 lb. per ton, a matter of nearly 20%. This reduced consumption of grinding media was one of the objectives set up when the Tricone mill started operation in 1948. The saving never materialized until now.

There is no question that the mill is doing better work under the conditions reported with a low ball charge, the worn liners, ball size and speed conditions as they are.

I think the reduction in ball consumption offers the key to solving the question of why low ball load is more efficient. We know that there is slippage between the shell and first layer of balls on the uptake side of the mill and there is also slippage between each succeeding layer of balls.

Bond has done some work on this subject and thinks that something in the order of 15% of the power in the shell is consumed on the first layer of balls. From there on approximately 10% of the power that is left in each layer of balls is consumed by the following layer of balls. This finally brings us to some point in the charge where there is very little power left to do useful work. This is easy to see in moving pictures of test mills with glass ends and is often referred to as the neutral point.

After contemplating this fact, I made the statement a few years ago that a mill 100 ft. in diameter would not grind eggs. That is, unless the diameter of the ball size was not increased proportionately. I still think this statement holds good, at least no one can prove that it is wrong. This is interesting to think about as the trend is toward bigger and bigger diameter mills. There certainly must be some mill diameter where power efficiency falls off with conventional size balls due to the well known fact described above. We can only transfer power from the shell through just so many layers of balls. The size and type of balls will govern this factor.

It will be remembered that Garms presented a paper some years ago describing the slow speed mills at Hayden. He brought out the point that the center of his ball charge was composed of a "mushy" mass of small worn-out balls that he termed the "kidney." To my question of whether the power used in slushing around this mushy mass of little balls was doing effective work, he replied characteristically "They wear out don't they?"

So I think the explanation as to why Mr. Lewis' low ball charge is doing better work is simply this: he has by empirical means found the number of layers of balls that most effectively consume the power in the shell. With his 1-in., smooth, steel balls this is apparently not a very big load. With a high ball charge the power from the shell was being transferred through approximately the same number of ball layers, thus leaving a big "loblolly" of balls in the kidney that were doing very little or no work, but that were wearing away by corrosion. It is to be remembered that on the high sulphide content of the T. C. ore corrosion is a large factor. Between the shell and the ball mass there is a drop of potential of .26 v.

I do not think that the large classifying pool is a contributing factor in this case. If you will again refer to the "Progress Report," AIME, Vol. 187, on pages 710 and 711, you will find in Tables IV and V a lot of information on this subject. The classifying effect was just as complete then as now, and no such improved efficiency developed as is now reported.

As for the lower xanthate consumption with the low ball charge, it follows that the lower ball consumption and a proportionately smaller amount of products of corrosion, require less xanthate to overcome the corrosion salts. This would definitely tend to improve the loss of copper and sulphur in the tailings. This I think is quite obvious unless it is known that the quantities of the products of corrosion are the same in both cases, which I doubt.

ADRIAN DORENFELD
Assistant Professor
of Mineral Dressing
University of Alabama

I BELIEVE that the explanation given is essentially correct. However, insofar as I can remember, the Tricone mill turns at a low speed—thus, there is little cataracting of the ball mass. Hence, having the large mass of balls (previous practice) did little good since the balls were grinding, near the center of the mill, already well ground and essentially finished material. Power was being consumed, as well as balls, with little gain.

The fact that liner wear is substantially less may be due to less weight of balls against the sides of the mill, so that balls do not come in contact with the liners as much as before. Of course, this is all predicated on recollection that the Copperhill mill does not cataract.

I believe that the findings at Copperhill mean that the new mill needs a different technique in operation—since the ball mill is not a conventional one, there is the possibility that the operating technique may not be conventional either!

What's Your Opinion?

If you have any comments on this Copperhill story, or if you have had a similar experience somewhere, *E&MJ* will welcome your contribution to a general discussion of this article. Please address your comments to:

The Editor
Engineering and Mining Journal
330 West 42nd St.
New York 36, N. Y.

T. M. MORRIS
School of Mines and Metallurgy
Rolla, Missouri

THE RESULTS SHOWN are certainly interesting. I do not know of any other operation in which tonnage ground through a given mesh increased as ball load was decreased below 45% of the mill volume.

I think that it would be worthwhile to know if the ball size distribution was the same after the ball load was decreased as before this change was made. In many grinding operations a very noticeable increase in tonnage through a given mesh has been obtained when the ball size distribution was changed. This may be a factor causing the improvement.

The increased pool area in the mill would augment the Hydroscillator pool area and should help the grinding. Previously reported data indicated that the return sands from the Hydroscillator were quite clean and hence it would seem as though increased classification capacity would not be wholly responsible for the results obtained.

Sequel

When Mr. Lewis has the opportunity to complete his investigation of the operation of his Hardinge Tricone mill, including further reduction of the ball loads, he has kindly agreed to publish the results. We are looking forward to another of the contributions to milling science which have become practically a tradition with the mill staff of Tennessee Copper Co.