DRY CRUSHING.

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As the selection of suitable crushing machinery is one of the most important matters to be decided in designing a gold milling plant, the author hopes that this paper, describing the different plants in use at Mt. Morgan, will be of interest to some members who may have a dry crushing problem to contend with. He may add that, as he was engaged in the erection and running of the large West Works plant, he has had considerable experience in Krupp Ball Mills, and at the same time has had ample opportunity of comparing their work with that of the other forms of crushers employed on the mine.

Many papers have been written lately on the question of treatment of slimes, chiefly in connection with Cyanide plants, and a variety of methods and apparatus have been devised to overcome the great difficulty caused by slimes during leaching operations. These are being employed, not only on works treating old tailings heaps (in which case they may be necessary), but also in works treating tailings direct from the mill. There is an old saying that "Prevention is better than cure," and, in the author's opinion, it would be better to pay more attention to the improvement of our present crushing machinery, with a view to preventing the formation of slimes, than to devote time and expense in trying to remedy an evil which should not exist.

From the results obtained with the Krupp Mills, working both on an ore very liable to form slimes and on hard Mundic stone, the author is of opinion that this class of machine is admirably suited for the crushing of all varieties of ore, and that any slimes formed are not sufficient to interfere with subsequent leaching. With the large 100-ton concrete vats at the West Works, the average time under solution is 33 hours, and under water 35 hours, making the total time for treatment 68 hours, with a vacuum of 5 lbs. The depth of ore in the vat is 3 feet, and the gravel and sand filter bottom 1 foot 4 inches. No special precautions are taken in filling a vat, the ore being simply dumped in from the trucks and levelled up when full. Under these conditions, and taking into account the class of ore, the average extraction of 91 % on a 10 dwt. ore shows how successful the Krupp

Mills are as dry crushers. At the Top and Lower Works no difficulty is experienced in leaching the Mundic ore, no vacuum being required, and, as the ore is richer and the gold somewhat coarser than in the oxidised stone, the outlet valves have to be closed, to give the necessary time for dissolving the gold.

The average time for treatment of the Mundic vats is 70 hours, for 64 of which they are under solution, leaving only 6 hours for cleaning off under water.

At the Top Works the vats of oxidised ore are under treatment for 30 hours, but the vats are small (20 tons) and a vacuum of 10 lbs., so that they cannot well be compared with the West Works.

Altogether, on the different works, there are 21 Ball Mill crushers, 20 of them being from the Krupp foundry, and one from the Otis works, Melbourne; while the older crushing plants at the Top and Lower Works comprise ten sets of "Krom" pattern rolls.

It will be convenient to describe, first, the different classes of ore sent to the different Mills; then the plants, and the conditions under which they work; and, lastly, to compare the work done in each case and the cost per ton of ore.

The Ore.

This may be divided into two main classes, viz., the *Oxidised* and the *Sulphide* or *Mundic*. The *Oxidised Ore* is a mixture of various grades of sinter, the so-called Kaolin, sugary quartz, and a small percentage of hard ironstone. They are all mined from various parts of the stopes and open cut, and the mixture is made so as to keep the average gold contents of the ore sent to the Mills at about one ounce per ton. The whole of this ore is of a light, friable description, easily crushed, and liable to form an excess of slimes. It contains a large percentage of moisture which is lost in the drying and roasting operations. The weight per cubic foot of roasted ore is about 71 lbs. This ore is confined to the Roll Mills at the Top and Lower Works. The ore sent to the Low Grade plant at the West Works is similar in character to the above, but is of low grade, the average being about 10 dwts. per ton, and, as most of it is taken from the old mine tips, it contains a larger percentage of moisture—12 % being allowed for this. The ore is very light, the crushed and roasted material being about 75 lbs. per cubic foot: so that the advantage gained in the softness is partly counteracted by the larger bulk which has to be handled.

The *Sulphide* or *Mundic* ore is mined from the deeper levels, and consists of a very hard bluish quartz, heavily charged with Iron Pyrites, and is probably as hard as any ore that is likely to be met with. It is practically impervious, and, as very little water exists in the Mine, it contains only a little surface moisture, which does not interfere with the crushing. The weight of the crushed ore is about 140 lbs. per cubic foot; its gold value varies greatly, running up to extremely rich ore, and the average sent to the Works is about 4 oz. per ton.

Crushing Plants.

Lower Works.—The old crushing plant at these Works comprises a set of 4 pairs of high speed Rolls of the "Krom" pattern, preceded by a large Blake Marsden crusher, and an externally fired steel shell revolving Drier. The plant is provided with the usual arrangements of screens, elevators, and storage hoppers, etc. The Rolls are 30 inches in diameter and 16 inches face. The ore is delivered directly from the Mine by an Ærial Cable Tramway into a main hopper, from which it gravitates to the breaker without further handling.

The Mill is badly arranged with regard to the roasting furnaces, so that much trucking is necessary, which adds considerably to the cost of treatment per ton. A 40 h.p. Davey-Paxman horizontal engine drives all the machinery, and is supplied with steam by 5 Cornish boilers 18 ft. long and 6 ft. diameter. The number of men employed on the Mill per day is as follows:—

Overseer	1
Foremen	3
Drivers	3
Firemen	9
Breaker-men	3
Drier-men	3
Mill-men	6
Repairers	1
Truckers	6
Total	35

The Single Ball Mill at the Lower Works is a No. 6, from the Otis foundry, Victoria, and is employed crushing Mundic ore. It was placed there temporarily to increase the output until the West Works were completed, and is consequently inconveniently arranged with regard to the furnaces, so that trucking is necessary.

The stone is carted by contract to the Mill, and is there hand-broken to a 3-inch gauge. No Drier is used, and the Mill is hand-fed. It runs at 22 revolutions per minute, and requires 12 h.p. for driving. The charge of balls is 15 cwt., and the wear of balls about $1\frac{1}{2}$ lbs. per ton of ore crushed. The power for this Mill is obtained from the main engine. The number of men employed per day is as follows:—

Hand-breaking (on day work) ...	2
Feeders	3
Truckers	3
Total	8

Top Works.—At these Works there are two separate crushing plants—one consisting of 6 pairs of Krom Rolls, crushing oxidised ore, and the other of 4 No. 4 Krupp Mills, working on Mundic stone. The ore for the Roll Mill passes from main hoppers to small Blake pattern

crushers, and is then dried in revolving Driers of the same type as at the Lower Works. The Rolls are provided with screens, etc., as usual. The same necessity for trucking to the furnace floor exists as at the Lower Works, but the distance is not nearly so great.

The men employed on this plant per day are as follows :—

Breakers	6
Driers	6
Mill-men	12
Drivers	6
Firemen	12
Truckers	12
Foremen	3
Overseer	1
Total	58

For the Ball Mills the ore is delivered to a separate main hopper, crushed to a 2-in. gauge in a small breaker (Blake), and trucked direct to a storage hopper above the Mills, no Drier being necessary.

The Mills are four in number (No. 4 Krupp), and are arranged as shown in Fig. 1, with the four feed ends coming together at the centre. Each Mill is driven separately, from a main shaft, by a counter shaft and spur gearing, connected to the main shaft by belting, and provided with fast and loose pulleys. As the two left-hand Mills are set in the opposite direction to the right-hand two, the driving belts of the former are crossed, and this makes the Mill revolve in the proper direction, and obviates the necessity of specially-built Mills (right and left), as at the West Works. This method of driving, although requiring more floor space, is preferable to that used at the West Works, as each Mill is independent and can be put in and out of gear with much greater ease and safety to the workmen.

The openings at the top of the Mill casings are connected by iron piping to a 45-inch Sturtivant fan, worked off the main shaft, and this carries off what little moisture there is and a small quantity of the finer dust.

The storage hopper is arranged above the Mills, and is in every respect similar to those at the West Works, as shown in Figs. 3 and 4.

The Mills run at 21 revolutions per minute, and take 10 h.p. each. The charge of balls is 1000 lbs., and the wear of balls about $1\frac{1}{2}$ lbs. per ton of ore crushed. The Mills are supported on wooden trestles of 12-inch x 12-inch hardwood, built sufficiently high from the ground to allow a truck to come under the hopper casing of the Mills. The ore from here has also to be trucked to the furnaces.

The number of men employed on the plant per day is as follows :—

Breakers	3
Mill-men	3
Truckers	9
Total	15

The Breakers and Driers of both plants are driven by a 20 h.p. horizontal engine, while the Rolls and Ball Mills are worked by a compound, non-condensing horizontal engine (Davey-Paxman) of 80 h.p. Steam is supplied by 6 Cornish boilers 28 ft. long and 6 ft. diameter.

West Works.—At the West Works the plant consists of sixteen No. 5 Krupp Ball Mills, placed in a long double line, and arranged on nests of 4 for feeding purposes, each nest being supplied from a separate hopper.

The main engine, which is a 400 h.p. triple expansion engine, fitted with condenser, etc., is placed at one end of the line of Mills, and is connected with the main shaft direct: the latter runs between the two lines of Mills, and gears right and left alternately by small pinions to the spur wheels on the Mill shafts. The pinions are arranged with clutch-gearing, etc., for throwing any Mill out of gear. This method of driving has the advantage of reducing the area of floor space required, which is important in a gravitation works, and the strains are evenly distributed on the main shafting; but as the pinions are liable to seize on the main shaft when a Mill is out of gear, and thus start it revolving, it is a source of danger to the workmen. Again, with clutch gearing, if one Mill is stopped, the whole plant has to be slowed down to put it into gear, which is a waste of time, and requires increased engine power to keep all the Mills revolving at the greatly reduced speed. The Mills themselves have also to be specially made to run clock-wise and counter-clock-wise, on account of being driven by a centrally-situated main shaft, which difficulty is obviated at the Top Works by simply crossing the belts of two of the Mills.

Fig. 2 shows a plan of the Mills, with method of driving. The main engine is supplied with steam from four Babcock and Wilcox boilers of 125 h.p. each. The working pressure is 150 lbs. per square inch, which is reduced by loss to 140 lbs. at the engine. The four boilers are connected to a main flue and a Loucock economiser.

The Mills take about 12 h.p. each, and run at 22 revolutions per minute. The charge of balls is 13 cwt. per Mill, and the wear of the balls about $1\frac{1}{4}$ lbs. per ton of ore.

For convenience of construction and running, the West Works were built in four separate sections, which work independently of each other; four Mills go to a section, and they are supplied with ore from a separate main hopper and by separate Breaker and Drier.

The first section has a large Blake-Marsden crusher, while sections 2, 3 and 4 are supplied with Gates machines. Revolving Driers are used throughout, the shells being of $\frac{1}{2}$ inch steel plate, and they are lined with fire brick, and are fired externally—*i.e.*, the heat from the fire-box, at the lower end, passes through the cylinder.

The class of ore sent to the Works must be thoroughly dry before going to the Mills, or there is danger of the screens becoming clogged.

No fan is used, and as the Mills all discharge into covered storage hoppers immediately below them, there is no loss or nuisance from dust. The crushing power of the four Mills is rather in excess of the roasting power of the revolving furnace, so that one Mill is often idle, and the monthly crushing returns could be increased if necessary. This, how-

ever, is also an advantage for repairing purposes, and serves as a reserve when specially good roasting ore is going through and it is necessary to keep the furnace fully supplied. Generally, too, by running the four Mills, towards the end of the week a supply of ore can be got on hand, and the whole crushing plant stopped for two or three shifts on Sunday.

The feeding arrangements for the Mills are very simple, and as follows :—

Over each set of four Mills a wooden box hopper is arranged, having a capacity of 100 tons; the bottom is built flat, which simplifies construction, and at the same time gives a reserve of ore, which can be hand-fed to the outlet holes if necessary.

There are two outlet holes, 2 feet square, in the hopper floor, each being situated centrally between the two Mills. Vertical shoots come down from these openings and end with bottoms of an inverted V shape, the continuation of which forms the shoots into the feed hoppers on the Mills. The sides of the vertical shoots are open for 2 feet, and are fitted with sliding W.I. doors and lever handles. The ore from the Drier is delivered to the centre of the hopper by a steel link-belt elevator; it forms its own slope to the two outlet holes, and all that is necessary in feeding any Mill is to lower the lever of the corresponding shoot, the door being easily closed when sufficient ore has passed out. One man is sufficient for 4 Mills, and his only duties are to keep the Mills properly fed, look after the bearings, and occasionally examine the crushed material leaving the Mills, to see that they are working properly. Figs. 3 and 4 show a front and side elevation respectively of the hopper, and Fig. 5 the detail of the feeding shoots.

The Mills are supported by a combination of concrete foundation walls and wooden trestles, about 40 feet above the ground level of the roasting floor. The trestles, which are built of 12″ x 12″ hardwood, are 21 feet high, and the concrete 19 feet. This arrangement allows room for a "fine ore" storage hopper below the Mills, and below that again the dust chamber of the revolving furnace. The "fine ore" hopper is made by completely lining the trestles with tongued and grooved boards, and the ore is fed directly from there to the dust chambers by a few 5-inch iron pipes, while the revolver automatically feeds itself and regulates the supply of ore from the hopper to its dust chamber. This does away with all the heavy expense of trucking and feeding.

Fig. 6 shows a front elevation, and Fig. 7 a side elevation, of the Ball Mill supports.

The number of men employed per day on the whole crushing plant of four sections is as follows :—

Breakers	12
Driers	12
Mill-men	12
Drivers	3
Helpers (boys)	3
Firemen	6
Total	48

TABLE *A* gives the total cost of crushing at the Top Works. The cost sheets are not kept separate for the two plants, but the running costs for each could be roughly calculated from the labour employed, and the maintenance for the Ball Mills could be taken at about the same as at the West Works.

TABLE *B* gives the total cost for crushing at the Lower Works, including the No. 6 Otis Mill. In both these cases the total cost is certainly reduced by including the Ball Mills, so that the crushing by Rolls is something over 6s. 7d. per ton, and although the trucking is an extra expense which is obviated in the West Works by a better arrangement of plant, there is still a large margin in favour of the latter works, *i.e.*, Ball Mills, and, moreover, it would be difficult to arrange a Roll plant without some trucking, on account of the large area occupied. The chief items of increased cost are the extra labour required in working and the high cost of maintenance.

TABLE *C* gives the detail costs of crushing and drying at the West Works, and it will be seen that the chief item of expense is the drying, where the firewood amounts to nearly 6d. per ton.

TABLE *D* gives a summary of all the plants, with their output, cost per ton, etc.

Table "A."

UPPER CRUSHER (TOP WORKS)

FOR SIX MONTHS ENDING NOVEMBER 30TH, 1897.

	£	s.	d.	£	s.	d.		Tons.	s.	d.
GENERAL—										
Wages	420	18	0				Ore Crushed	29,569		
Stores	316	16	8							
Electric Light	78	5	8							
General Expenses	110	18	5							
Water Supply . ..	95	12	2							
Tons. Cartage	0	2	4							
4601 @ 13/- Billet Wood	2813	14	5							
99 @ 18/- Firewood	39	18	0							
				7676	5	8	Cost per ton		5	2.3
MAINTENANCE—										
Wages	482	16	11							
Stores	1144	1	7							
Timber	21	15	5							
Mechanics' Work	523	18	4							
				2172	12	3	Cost per ton		1	5.63
			Total	£9848	17	11	Total Cost per ton		6	7.93

Table "B."

LOWER CRUSHER

For Six Months ending November 30th, 1897.

	£	s.	d.	£	s.	d.		Tons.	s.	d.
GENERAL—										
Wages	2100	6	6				Ore Crushed	15,654		
Stores	186	9	4							
Firewood	150	8	9							
Billet Wood	1051	16	10							
Cartage	16	6	7							
Water Supply	95	12	2							
General Expenses	63	0	8							
Electric Light	47	8	10							
				3711	9	8	Cost per ton		4	8.9
MAINTENANCE—										
Wages	341	16	11							
Stores	662	14	8							
Cartage	5	11	2							
Timber	24	16	10							
Mechanics' Work	447	5	1							
				1482	4	8	Cost per ton		1	10.72
			Total	£5193	14	4	Total Cost per ton		6	7.62