TOWER FINE MILLING EXPERIENCE AT MOUNT ISA MINES

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Abstract -. Over the last ten years Tower mills were studied and used for regrinding and fine grinding applications at MIM operations. They were found to be more energy efficient than regrinding tumbling ball mills, more reliable, and easy to operate and maintain. Tower mill grinding efficiency drops as feed material becomes finer then 25 microns due to high ball/particle size ratio. Fine grinding efficiency greatly increases with finer media and slightly with denser slurries. To achieve efficient grinding, closed circuit with hydrocyclones is needed. High cyclone efficiency greatly improves the performance of the circuit. A new procedure for Tower mill simulation and scale-up has emerged recently.

Introduction

The Tower mill is a vertical stirred grinding mill which can be used in both dry and wet grinding applications. It has provided a means of size reduction in an area where conventional tumbling mills become inefficient (Morrell et al, 1993). The major advantage of the Tower mills over the ball mills in regrinding and fine grinding operations is an efficient utilisation of the fine grinding media. The normal top size of media used is 10 - 25 mm but for very fine grinding even smaller media can be used. Tower mills were first introduced in the 1950s as an alternative to the ball mills in a regrinding application. Since then they have been used to grind a range of materials from limestone to coal to sulphide concentrates. A Tower mill can be installed for a fraction of the cost of an equivalent kilowatt ball mill. The maintenance costs and availability of the Tower mill are the same when compared to the equivalent ball mills (Ramsey, 1982; Stief, 1987). Several Australian companies have installed Tower mills as a device that can produce a fine product with a significantly lower power draw (Glen et al, 1991).

The mineralogical complexity of the Mount Isa and Hilton ores is such that they require very fine grinding in order to liberate the major minerals, galena and sphalerite and achieve economical separation in flotation (Young et al, 1997). The conventional regrinding ball mils were not suitable as they become extremely inefficient as the grinding product size P_{80} falls below 45 μm. A study conducted in the Mount Isa zinc regrinding circuit showed a pilot Tower mill to have superior performance compared to the existing ball mill regrinding circuit (Pfaller, 1990). After detailed testwork conducted by Kubota Tower Corporation and MIM personnel, Tower mills were installed in both the Hilton and Mount Isa lead zinc concentrators.

Table 1. Tower mill circuit equipment data

Tower Mill	Hilton	Mount Isa
Make	Kubota Tower Mill	Kubota Tower Mill
Model	KW-250	KW-700 F
Motor	190 kW	520 kW
No load power	23.9 kW	45 kW
Internal recycle pump	Warman, 110 kW	Warman, 110 kW
Make up grinding balls	12 mm, chrome steel	12 mm, chrome steel
Medium consumption	0.5 kg/t	0.4 kg/t
Inside diameter	1.74 m	2.71 m
Hight	4.55 m	5.4 m
Mill volume approx.	9.54 m^3	31.1 m^3
Medium volume approx	3.2 m^3	12 m^3
Hydro-cyclones		
Make	Krebs	Warman
Model	D10BB	6C
Number operating	1	3 - 5
Diameter	250 mm	150 mm
Length	190 mm	220 (400)mm
Inlet diameter	70 mm	36 (50x20)mm
Vortex finder diameter	81 mm	60 mm
Spigot diameter	22 mm	40 (45)mm
Cone angle	12° (deg)	10° (deg)
Operating pressure	up to 250 kPa	up to 250 kPa

Tower Mill Installations by Mount Isa Mines

Hilton Operation

The Hilton concentrator commenced operations in December 1989, reaching target metallurgical performance by mid-1990. The 220 kW Tower mill (Table 1) was installed to regrind the underflow from the zinc and lead cyclones for subsequent treatment in the Low Grade Middlings (LGM, or bulk lead-zinc concentrate) flotation section (Rohner, 1993). The mill operated in closed circuit with one Krebs hydrocyclone and was charged with 12.7 mm diameter high-chrome steel balls (Rohner, 1993). The part of the circuit flowsheet containing the Tower mill is presented in Figure 1.

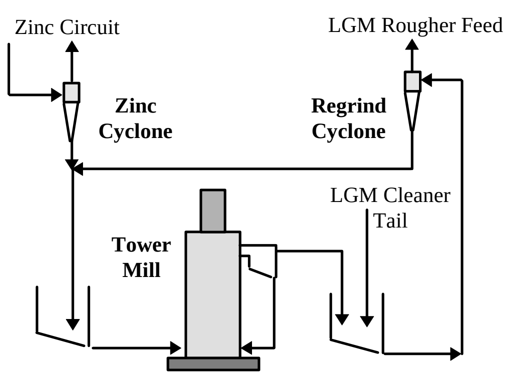

Figure 1. Hilton Tower mill regrind circuit

Mount Isa Pb/Zn Concentrator

MOUNT ISA MINES LIMITED - LEAD/ZINC CONCENTRATOR FLOTATION FLOWSHEET

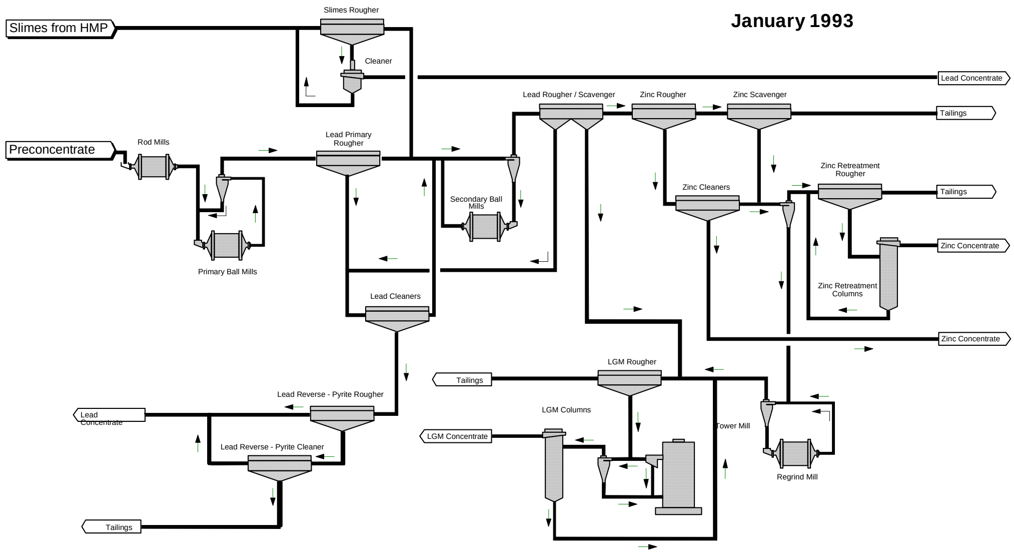

Figure 2. Flowsheet after the installation of increased grinding and flotation capacity- After Young et al, 1997

The lead-zinc ore from the mine at Mount Isa has become more difficult to treat in recent years. Efforts to restore performance in the Lead-Zinc concentrator led to the doubling of the total grinding capacity. A KW-700F Tower mill was installed in the LGM circuit (Figure 2) during 1991 as a part of this effort. Several projects have been undertaken since then to eliminate the LGM concentrate production. These included the installation of new fine grinding technology (the ISAMill) at the end of 1994. With the installation of the two ISAMills, the Tower mill was shifted to the zinc retreat circuit (see Figure 3).

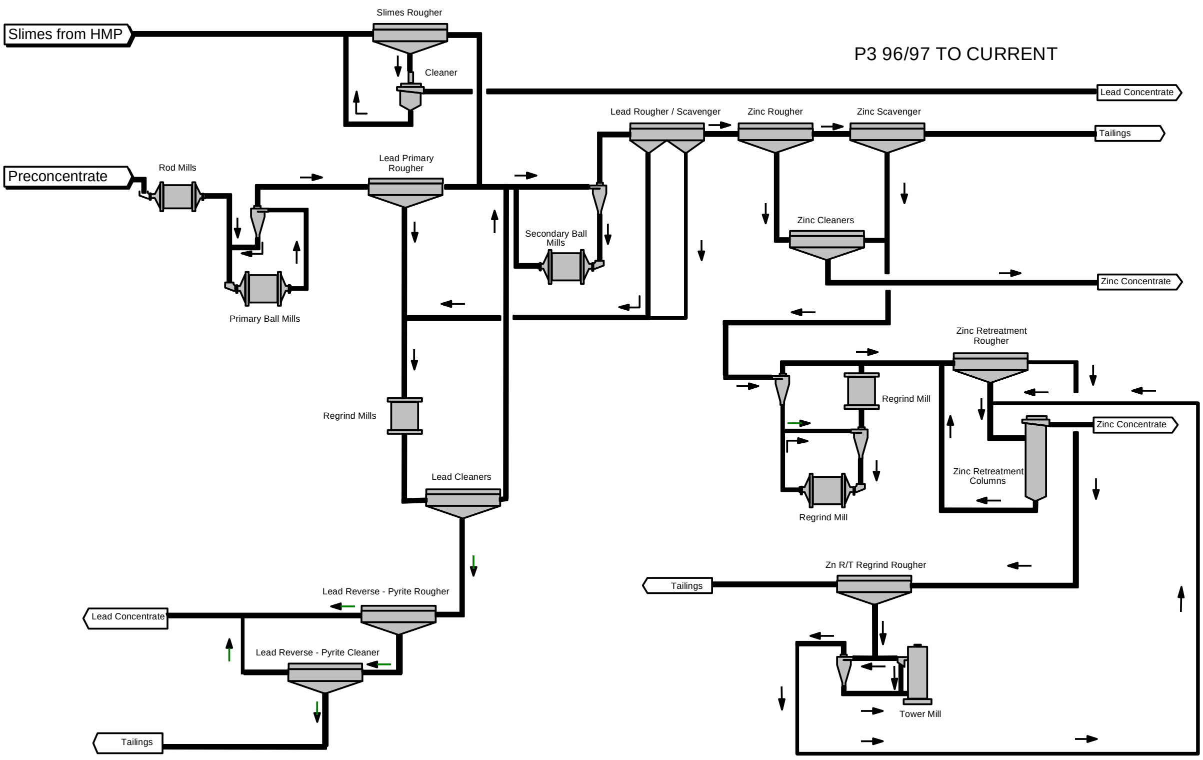

Figure 3 - Current flowsheet after the installation of regrinding of lead rougher and zinc concentrate

Operation of the Hilton and Mount Isa tower Mills

The metallurgical performance of the Tower mill can be assessed from the feed and product size and the mill power draw. Data for the Hilton and Mount Isa Tower mills in the LGM circuits are taken from the AMIRA P336 project "Methods and Benefits of Fine Grinding Ores" (progress reports 1993,1994). Summaries of the results are presented in Tables 2 to 4. The Tower mill circuit (Tower mill+hydrocyclone) and the mills' own performances are presented separately in order to assess the importance of classification in regrinding and fine grinding operations.

Table 2. Tower mill circuit performance at Hilton concentrator

Mill gross power 164 kW	**Circuit Feed**	**Circuit Product***	**Mill Feed****	**Mill Discharge**
Solids flow t/h	12.3	12.3	16.2	16.2
% solids	68.9	26.0	64.6	63.0
80% passing size	112.0	39.2	97.0	38.9
Spec. net energy kWh/t	circuit→	11.4	mill→	8.64
Operating index Wo kWh/t	circuit→	20.3	mill→	17.3

(*) cleaner con + rougher tail ; (**) zinc cyclone U/F + Tower mill cyclone U/F

The Hilton regrind circuit was unusual, as the LGM (low grade middlings) cleaner tail flow was added to the Tower Mill cyclone feed sump and was large in volume relative to the fresh feed flow. The size distribution of the LGM cleaner tail was similar to that of the regrind cyclone overflow, so the LGM cleaner tail stream essentially passed straight to the regrind cyclone overflow and only assisted to dilute the cyclone feed. This performance of the regrind circuit was similar to that which would be achieved if the Tower mill was in open-circuit, treating only the zinc cyclone underflow.

The size reduction was high (>2.5) and the operating work index (Wo) was close to the Hilton ore Bond work index (Wi =17 kWh/t) suggesting efficient Tower mill grinding. The efficiency arose from the small ball size and relatively coarse feed and coarse product. The mill+cyclone circuit had a higher operating work index relative to the mill, indicating inefficient cyclone operation. A high vortex-finder/spigot diameter ratio (81/22 mm) caused a very low water and solid split to underflow (9%) and a low coarse particle recovery to underflow (< 60%, see Figure 4). The use of 250 mm diameter cyclones led to a coarse cut size (d_{50}) of 90 microns. This was much coarser than in the 150 mm cyclones used at the Mount Isa Lead-Zinc Concentrator.

Table 3. ISA Tower mill circuit performance in the LGM circuit

Mill gross power 454 kW	**Circuit Feed**	**Circuit Product***	**Mill Feed****	**Mill Discharge**
Solids flow t/h	75.0	75.0	43.7	43.7
% solids	42.6	40.7	59.8	59.8
80% passing size	17.4	12.7	24.1	18.3
Spec. net energy kWh/t	circuit→	5.45	mill→	9.36
Operating index Wo kWh/t	circuit→	14.8	mill→	34.6

(*) Cyclone O/F ; (**)Tower mill cyclone U/F

The Mount Isa Lead-Zinc Concentrator Tower mill is used for fine grinding of fine grain particles near the tail of the circuit. It had a similar performance in both the LGM circuit (Table 3) and the current zinc retreatment circuit (Table 4). The circuit operating (mill+cyclones) index was low in both applications suggesting efficient size reduction. This was mainly due to the efficient cyclone operation in this fine particle range.

The mill operating index was higher in the Mount Isa circuit than in the Hilton circuit (~100%), due to the finer feed and product size. This reflects difficulties associated with the fine particle breakage (increased particle strength) as well as an unfavourable ball/particle size ratio. The use of finer media would improve the milling efficiency, but may increase ball consumption and iron contamination of the product, affecting flotation performance. The lighter ball weight would cause balls to be floated out of the mill at higher slurry densities and upward velocities.

Table 4. ISA Tower mill circuit performance in the zinc retreat circuit

Mill gross power 427 kW	**Circuit Feed**	**Circuit Product***	**Mill Feed****	**Mill Discharge**
Solids flow t/h	36.2	36.2	35.5	35.4
% solids	40.4	36.4	60.0	60.0
80% passing size	19.9	12.0	34.7	23.9
Spec. net energy kWh/t	circuit→	11.1	mill→	11.4
Operating index Wo kWh/t	circuit→	18.3	mill→	34.6

(*) Cyclone O/F ; (**)Tower mill cyclone U/F

The hydrocyclone classification efficiency dictates the performance of the regrinding circuit. The role of the hydrocyclone is to remove the final product from the closed circuit grinding and increase the size and density of the mill feed slurry. The cyclone performance can be assessed using the data presented in Table 5 and efficiency curve shown in Figure 4. The efficiency curves were obtained using the raw sizing data and the separation efficiency model fitting.

Table 5. Tower mill cyclone performance

	Hilton			**Mount Isa, LGM**			**Mount Isa, ZnR**		
	feed	**O/F**	**U/F**	**feed**	**O/F**	**U/F**	**feed**	**O/F**	**U/F**
solids t/h	42.4	38.7	3.7	118.7	75.0	43.7	72.0	36.5	35.5
% solids	46.1	40.6	54.6	47.7	40.7	59.8	45.4	37.3	60
P_{80} μm	36.3	34.8	53.9	17.3	12.5	23.5	22.6	12.0	34.3
water split %		94			79.7			82.4	
d_{50c} (μm)	138			20.8			17.5		
α	3.5			3.6			3.7		

Note: α - sharpness of classification

The sharpness of the separation depends on the slope of the central portion of the efficiency curve The α parameter is related to this slope. Values of α lower than one indicate poor separation, whilst high values (greater than four) correspond to very good separation. The classification cut point is defined through the d_{50c} value, smaller values indicating finer cut. The water split also indicates the efficiency of the cyclone in terms of its ability to recover water to the overflow fraction. High values indicate good water recovery and hence limited entrainment of fines in the underflow fraction.

The Mount Isa Lead-Zinc Concentrator Tower mill cyclones in the LGM and the zinc retreatment circuits had similar performances. This could be expected as the same cyclone was used in both circuits and similar material was treated. The sharpness of classification (α) and water recovery to cyclone overflow were high suggesting an efficient classification with less then 30% of fines (minus 10 μm) reporting to cyclone underflow. This favourable separation performance enhanced grinding in the Tower mill circuit.

The performance of the Hilton Tower mill cyclone was unusual. The sharpness of classification and water recovery to cyclone overflow alone may suggest an efficient classification, but the efficiency curve shows poor performance. Less than 10% of the cyclone feed solids reported to the cyclone underflow, causing poor recovery of coarse particles and coarse cut size. This was mainly due to the cyclone dimensions and ,as discussed earlier, unusual regrind circuit set-up.

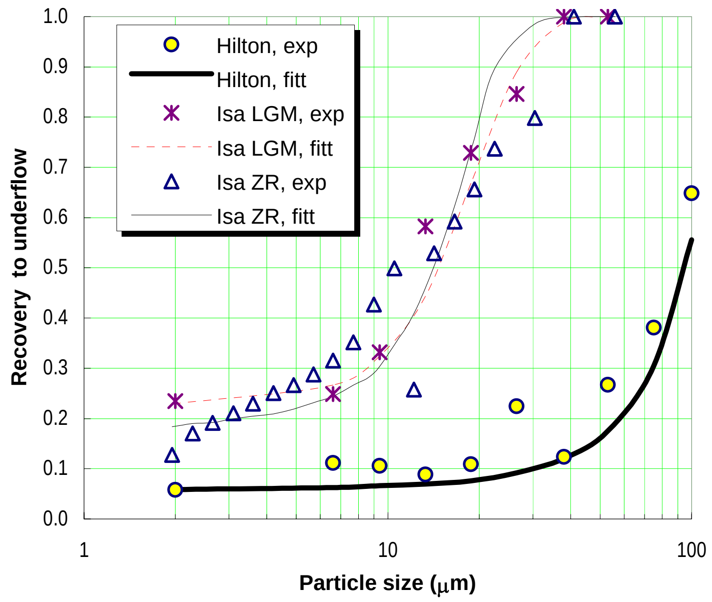

Figure 4. Cyclone performance

Maintenance

The Tower mill at the Mount Lead-Zinc Concentrator has proven reliable. The mill is inspected every 4 months and the digging-tips' liners are replaced. These are made of 18.2.1 white iron supplied by Mason and Cox. The full set of screw liners is replaced every 8 - 12 months. Protective plates and bars have been replaced twice in the life of the mill. The original keeper plates for the liners were mild steel and only lasted 12 months; the new keepers were made of 360 Brinell steel and last approximately 36 months.

The tonnage treated by the mill has decreased over time, due to the improved performance of the zinc circuit, causing only one of two installed injection nozzles to be operated. This increased the feed velocity into the mill, which is required to stop the head in the mill causing balls to travel back into the feed pump. The temperatures of the screw shaft bearings are continuously monitored and have not been replaced since mill commissioning.

The grinding medium has to be removed from the mill for the mill to be inspected. The medium is discharged directly into kibbles through the medium port. Once the medium is removed, inspection and maintenance can be undertaken through the main access door. The complete inspection, including the medium removal and return, can be achieved in 8 hours with a crew of three people. It is being carried out during planned concentrator shut-downs and availability can be considered 100%.

Milling Efficiency

The unique screw stirring action results in the grinding medium being well mixed, regardless of size. The Tower mill can efficiently use much smaller grinding media than regrinding tumbling ball mills where make-up media smaller than 25 mm are not viable. The make-up grinding medium size at the Mount Isa Lead-Zinc Concentrator Tower mill installation is 12.7 mm although even smaller media could be used to achieve very fine grinding. The downstream flotation problems associated with wear of the steel medium causing the particle surface chemistry properties to change are reduced by using the high-chrome steel grinding balls, supplied by Magotteaux.

The effect of medium size on efficiency of a pilot Tower mill grinding calcite is shown in Figure 4a. It can be seen that the smaller medium becomes more efficient as grinding product size becomes finer. Running the mill at higher slurry per cent solids can also be beneficial (Figure 4b).

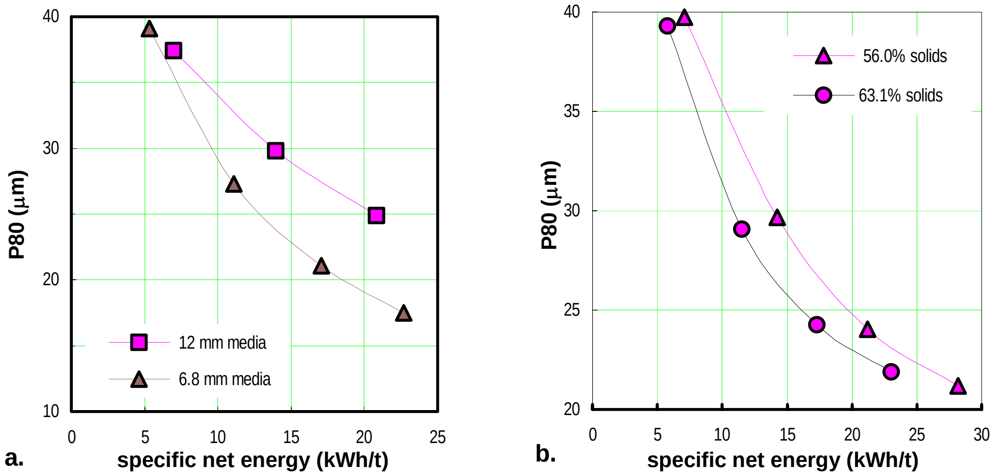

Figure 4: Media size (a) and slurry % solids (b) effect on pilot Tower mill efficiency (Jankovic, 1998)

The superiority of Tower mill energy efficiency over tumbling ball mills is well documented (Ramsey, 1982; Stief et al 1987; Menacho and Reyes, 1989). Detailed test work conducted in the Mount Isa LGM regrind circuit, consisting of two ball mills, (Pfaller, 1990) has confirmed that the pilot tower mill is more efficient than existing regrind ball mills. To obtain the product size P_{80}= 49 µm, from feed size F_{80}= 70 µm, pilot tower mill energy consumption was 3.6 kWh/t, while the regrind ball mill circuit energy consumption was 12.5 kWh/t. This superior performance is due to much smaller medium size (6 mm in the pilot tower mill, versus 38 mm in the regrind ball mills).

Modelling and Scale-up

In the last decade Tower mills have become increasingly common in the Minerals Processing industry. However, to date there has been only a limited amount of work published regarding Tower mill modelling and scale-up. The perfect mixing population balance model is relatively simple and is used for ball mill modelling. It can also be used for describing the Tower mill performance (Morrell, 1993; Menacho, 1989).

A more sophisticated approach is needed to describe the physical behaviour of the Tower mill and how it is related to particle size reduction. A detailed research program was carried out at the Julius Kruttshnitt Mineral Research Centre (JKMRC) in order to understand the physical behaviour of the Tower mill and how it is related to particle size reduction (Jankovic, 1998). Models were developed from this research to describe the media motion patterns and velocities inside the mill. The position and strength of forces in the mill were identified and related to mill design and operational conditions. A model to calculate mill power was developed based on medium velocities and forces.

Fine particle breakage patterns were studied using a novel device designed to mimic breakage under conditions similar to those in Tower mills. A method was developed to calculate the rate at which the medium collides. The rate of particle breakage in the Tower mill is related to this collision rate. A model was developed using these approaches, and laboratory Tower mill results were used to predict pilot scale results. The product size distributions of the experimental and simulated data were in good agreement. It is believed that full size mills can be successfully simulated using this model and results from laboratory size units.

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