ENERGY SAVINGS AND TECHNOLOGY COMPARISON USING SMALL GRINDING MEDIA

M Brissette

ABSTRACT
Considering the complexity of minerals, the need for finer grinding is increasing along with the energy cost. However, energy is increasing exponentially when grinding finer with conventional grinding balls. The use of small grinding media represents the best potential to improve energy efficiency. Today, it is possible to use grinding media as small as 1 mm. How do they perform in industrial grinding mills?

The use of small grinding media (5 - 12 mm), called Millpebs, in regrind mills proved that finer grinding can be achieved at lower energy consumption. In ball mills, energy savings vary from 10 per cent to 40 per cent compared to 25 mm media. A regrind ball mill with a mix of small grinding media can be as energy efficient as an Isa Mill charged with 2.5 and 3.5 mm beads. In vertical stirred mills, energy savings vary from 30 per cent to 60 per cent. To carry out the same final grind, a vertical stirred mill with Millpebs will consume at least 60 per cent less energy than a ball mill using 25 mm grinding media. More potential savings were identified.

To achieve those improvements, some operating conditions must be met: 1) feed size should be less than 250 μm; 2) the pulp must be fluid enough; 3) finally, the slurry linear velocity should not be excessive. This paper talks about all those industrial results improvement and operating conditions.

Keywords: fine grinding, small media, energy savings, vertical stirred mill, ball mill
Pulp density
Table 1 shows that the ejection of small media, monitored at many plant sites, depends mainly on pulp density, expressed in percentage solids by weight. A difference of 2 per cent to 4 per cent is enough to cause the discharge of the media. Below a critical value, the small media are staying in the mill. Diluting the pulp with water at mill’s inlet stops the ejection rapidly.

<table>
<thead>
<tr>
<th>% Solid by weight</th>
<th>Goldstrike tertiary</th>
<th>QCM regrind</th>
<th>IOC regrind</th>
<th>Duck pond secondary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore type</td>
<td>Au</td>
<td>Fe</td>
<td>Fe</td>
<td>Cu-Zn-Pb</td>
</tr>
<tr>
<td>No ejection</td>
<td>64%</td>
<td>77%</td>
<td>76%</td>
<td>76%</td>
</tr>
</tbody>
</table>

Ball fraction of mill volume
Table 2 shows that for nearly the same filling, measured physically, the mill power with smaller media is significantly reduced. Therefore, if the power is kept on target when adding small media, the charge will increase and may cause mill’s overcharging, specially if the charge is already at the trunnion level. One should be careful to reduce the power target when converting a charge from larger to smaller grinding media.

<table>
<thead>
<tr>
<th>Mine</th>
<th>Gold-copper mine</th>
<th>Secondary</th>
<th>Brunswick</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill type</td>
<td>Regrind</td>
<td>Secondary</td>
<td>CuPb regrind</td>
</tr>
<tr>
<td>Media</td>
<td>30 mm</td>
<td>Millpebs</td>
<td>Millpebs</td>
</tr>
<tr>
<td>Volume fraction</td>
<td>16.5%</td>
<td>33.0%</td>
<td>36.8%</td>
</tr>
<tr>
<td>Power</td>
<td>50 Amp</td>
<td>900 kW</td>
<td>550 kW</td>
</tr>
</tbody>
</table>

Flow rate
There is a limit on the flow rate of slurry that a ball mill can handle, specially when processing extremely high tonnage. McIvor (1990) recommends that the linear velocity of slurry in a ball mill should be less than 5 m/min to avoid mill overloading and balls be washing out of the mill. So far, small media have stayed in industrial mills for velocities up to 3.3 m/min when operating at the proper pulp density.

Small media were introduced in one 800 HP and two 1250 HP Vertimills without any media discharge incident. As shown in Figure 1, feed rate of one of the 1250 HP was as high as 830 TPH with a pulp density varying between 40 per cent and 60 per cent solids by weight.

To be noted that the reduction ratio calculated at the mill is almost constant above 400 TPH regardless of the ball size (Millpebs, 12 mm and 25 mm), the ore type (Cu-Mo vs Zn-Pb ore) and the feed size (below 140 μm versus above 350 μm). This can be easily explained by an extremely low residence time. It might also indicate that the equipment’s capacity is exceeded. When grinding is not needed, it is an excellent solution for creating surface, commonly called refresh milling.

Feed size
The most important parameter to determine the required size of grinding media is the feed size. In Figure 2, the specific breakage rate was calculated by Bazin, Parent and Chevalier (2004) and Bazin (2008a) for two industrial ball mills. The specific breakage rate of Millpebs are higher than the 25 mm media when the particle size is less than 250 μm regardless of the ore type (Fe and Cu-Zn-Pb), the Bond Index (12 and 23 kWh/t) and Millpebs’ proportion (20 per cent and 100 per cent).

The selection of the ball size is already summarised by McIvor (1997). Table 3 shows that energy efficiency is improved from 10 per cent to 40 per cent when Bond is recommending balls smaller than 12 mm and the feed size is less than 150 μm.
When all three operating criteria are met and the feed size is appropriate, small media can be added to the mill to reduce energy consumption or grind finer. The most common methodology to evaluate grinding efficiency is the Operating Work Index (Bond, 1961). A second method is to calculate the breakage rate using the perfect mixing ball mill model but it does not take into account the mill’s power. That variable is introduced in the specific breakage rate, expressed in t/kWh (Bazin, 2008a).

For small mines, resources are sometimes limited to perform extensive surveys. The feed rate in regrind circuit is rarely measured and much often, unknown. It is much easier to monitor the P80 of the cyclone overflow and adjust the mill’s power accordingly. No extra resources are needed and existing production data can be used. When multiples mills are operating in parallel, the power of

**TABLE 3**

Energy efficiency improvement in ball mills with small media.

<table>
<thead>
<tr>
<th>Application</th>
<th>Ore Type</th>
<th>BWI kWh/t</th>
<th>F80 μm</th>
<th>Bond Ball Top Size</th>
<th>% Millpebs</th>
<th>Energy Savings</th>
<th>Finer Grind</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary ball mill</td>
<td>Cu-Zn-Pb</td>
<td>12.0</td>
<td>93</td>
<td>8 mm</td>
<td>100%</td>
<td>-36%</td>
<td>Same</td>
</tr>
<tr>
<td>Regrind ball mill</td>
<td>Cu-Pb</td>
<td>12.0</td>
<td>30</td>
<td>5 mm</td>
<td>100%</td>
<td>-37%</td>
<td>Same</td>
</tr>
<tr>
<td>Regrind ball mill</td>
<td>Cu-Zn-Pb</td>
<td>10.0</td>
<td>40</td>
<td>5 mm</td>
<td>100%</td>
<td>-40%</td>
<td>Same</td>
</tr>
<tr>
<td>Regrind ball mill</td>
<td>Au-Cu</td>
<td>9.5</td>
<td>90</td>
<td>6 mm</td>
<td>100%</td>
<td>-39%</td>
<td>Same</td>
</tr>
<tr>
<td>Regrind ball mill</td>
<td>Au</td>
<td>18.0</td>
<td>130</td>
<td>8 mm</td>
<td>30%</td>
<td>-10%</td>
<td>+5%</td>
</tr>
<tr>
<td>Regrind ball mill</td>
<td>Cu</td>
<td>N/A</td>
<td>130</td>
<td>N/A</td>
<td>30%</td>
<td>-15%</td>
<td>+10%</td>
</tr>
<tr>
<td>Secondary ball mill</td>
<td>Fe</td>
<td>N/A</td>
<td>125</td>
<td>N/A</td>
<td>30%</td>
<td>-15%</td>
<td>Same</td>
</tr>
</tbody>
</table>
the mill containing the tested media is adjusted to have both the same discharge product. All regrind process flowsheets are available in previous papers (Brissette, 2009a; 2009b).

**Ball mill**

*Case 1 – secondary and regrind ball mills in copper-zinc-lead mine*

The choice of grinding media size to achieve fine grinding efficiently in the range of 15 to 25 μm has always been a concern at Brunswick Mine (Staples et al., 1997). Because the recommended Bond size of 8 mm was considered below practical limits, the use of a corrected make up size formula by Azzaroni (1981) and breakage function were chosen as methodology to optimise ball sizing. Cooper et al. (1993) chose the 25 mm slug because they were more cost effective than balls even if Herbst and Lo (1989) demonstrated that balls are generally 10 per cent to 15 per cent more efficient than conical shape (slugs).

Because the K80 of the cyclone underflow was 112 μm for the secondary ball mills and 44 μm for the CuPb regrind mill, a charge of 100 per cent Millpebs was tried in one mill of both grinding circuits. Bazin (2008a; 2008b) showed that power was reduced by 36 to 37 per cent in both cases to achieve the same grind product.

*Case 2 – regrind ball mill in gold-copper mine*

Flotation laboratory test demonstrated that if the grind target was changed from 40 μm to 20 μm, more gold would be liberated. The idea was to test different sizes of grinding media to get the best grinding efficiency.

In Table 4, the 19 mm and the 25 mm slugs led to the same gold rejection of 1.90 gr/ton at the cleaners tails as the 30 mm balls (Brissette, 2009a). It shows that all those media sizes were not efficient enough to grind finer. When the mill was shutdown for almost one month, the gold rejects increased to 2.69 gr/ton. Therefore, the regrind mill was necessary to improve gold recovery.

The best result was achieved with Millpebs when the P80 of the cyclone overflow was 27 μm. At lower charge, the gold contents at cleaners tail were still lower for nearly the same P80 as the 30 mm balls. In fact, the particle size distribution from the small media contained more fines, better measured by the Blaine number. Commonly used in the cement and the iron ore mining industries, the Blaine measures the ore’s particle surface per unit of weight in cm²/g. The lower gold content of the cleaner’s tailing was directly linked to the higher amount of fines.

**Vertical stirred mill**

*Case 3 – regrind mill in copper-molybdenum mine*

To decrease the grinding cost, a mix of 50 per cent Millpebs and 50 per cent 25 mm balls were introduced in one of the two parallel vertical mills. The average power draw was 625 kW with a mill’s throughput varying between 270 TPH and 650 TPH. The tonnage was calculated from a flow and density meter installed at the outlet of each feed pump.

When all the operating parameters taken at the mill are combined together (kW, TPH, F80 and P80) in Figure 3, the Millpebs mixture requires much less energy (1.0 kWh/t vs 1.6 kWh/t) to obtain the same reduction ratio as the 25 mm balls. When both mills were operating at the same power,
the mill containing the Millpebs mix was performing with a 31 per cent higher throughput (498 vs 380 TPH).

**Case 4 – regrind mills in copper-gold mine**

A new charge of Millpebs was entirely introduced into a 800 HP Vertimill by Brissette (2009a) to replace the existing 25 mm balls charge. In Table 5, power was reduced by 33 per cent to have the same grind of 75 per cent passing on 44 μm at the cyclone overflow. However, the surprise come from the fact that having a coarser grind of 53 per cent passing on 44 μm was leading to the same grade in the final concentrate with higher gold recovery. Total energy savings was 61 per cent. Being even coarser was decreasing gold recovery. However, further investigation is needed to better understand what happened.

**TABLE 5**

Industrial results of Millpebs in a 800 HP Vertimill of a Cu-Au mine.

<table>
<thead>
<tr>
<th>Media</th>
<th>25 mm</th>
<th>Millpebs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of days</td>
<td>31</td>
<td>6</td>
</tr>
<tr>
<td>Power (kW)</td>
<td>588</td>
<td>395</td>
</tr>
<tr>
<td>Energy consumption (kWh/t)</td>
<td>2.22</td>
<td>1.49</td>
</tr>
<tr>
<td>% 44 μm at overflow</td>
<td>75.4</td>
<td>74.3</td>
</tr>
<tr>
<td>Final Cu concentrate grade</td>
<td>31.1</td>
<td>30.9</td>
</tr>
<tr>
<td>Gold recovery</td>
<td>72.9</td>
<td>68.0</td>
</tr>
</tbody>
</table>

**INDUSTRIAL TECHNOLOGY COMPARISON WITH SMALL MEDIA**

**Ball mill versus vertical stirred mill**

No industrial ball mill was ever replaced by a vertical stirred mill in the past. In the previous case, the mine is operating two production lines having both similar primary grinding and flotation capacity. The difference resides in the regrind mills. A 2500 HP ball mill was installed in the first production line when the concentrator was initially built and a 800 HP Vertimill was installed in the second line when the concentrator capacity was increased. Both mills were using 25 mm balls with similar operating conditions (265 TPH at 75 per cent -44 μm) with the same ore.

Figure 4 shows that with 25 mm balls, the 800 HP Vertimill is drawing 44 per cent less power than the ball mill (587 kW vs 1045 kW). This value corroborates with previous studies of Stief, Lawruk and Wilson (1987) and more recently, Nesset *et al* (2006). Since, the ball mill was replaced by a second Vertimill of 1250 HP and commissioned with 25 mm balls. Surprisingly, that mill is performing like the 800HP Vertimill with Millpebs. More saving can be expected when small media will be added in the newer 1250 HP Vertimill.
Ball mill versus ISA mill

In March 2006, extensive maintenance was conducted on the 4.1 MW regrind ball mill at Kumtor Gold Mine of Centerra Gold, located in Kyrgyz Republic. To continue production, the IsaMill was used instead during four weeks for a coarser grind duty: the F80 was 135 μm instead of 20 μm. Although results were inconclusive because of different product size, Pease et al (2006a) and Shi et al (2008) showed some potential for this technology in regrind applications because the energy efficiency decreased from 40 kWh/t with a P80 of 18 μm to 24 kWh/t for a P80 of 60 μm. No optimisation was conducted although the media appeared too fine for this coarser duty.

In October 2008, Millpebs were introduced by Brissette (2009b) in Kumtor regrind mill in order to provide a finer feed (>90 per cent – 20 μm) to the IsaMill. Tonnage is directly measured at the regrind cyclone overflow feeding the Isa Mill. The Millpebs proportion reached about 25 - 30 per cent before running out of on-site inventory and lack of control in mill’s pulp density. In Table 6, a fraction of small media in the 25 mm balls charge decreased the energy consumption from 42 kWh/t to 25 kWh/t by maintaining the final grind target at 18 μm. Based on the Operating Work Index, the use of small media gave the best efficiency. The higher circuit tonnage was attributed to the higher plant feed rate but the fact that the grind had kept the target of 90 per cent can only be attributed to the smaller media. After the trial, the grind target was not reached even at higher power and lower feed rate.

Vertical stirred mill versus ISA mill

So far, no vertical mill has been replaced by an Isa Mill. Both technologies were compared at Mount Isa by Gao, Young and Allum (2002). The Isa Mill showed a sharper particle size distribution than the Tower mill but efficiency (kWh/t) is not shown, neither a Operating Work Index comparison.

Since 1999, as reported by Pease et al (2006b), the 520 kW Tower Mill of Mount Isa is in operation to prepare the feed of the two 1.1 MW Isa Mills to grind from a F80 of 37 μm to a P80 of 12 μm. The total installed power is 2720 kW. Before the process changes for the new George Fisher ore body, the total power of the previous grinding configuration to grind from 37 to 12 μm was 1270 kW by using a conventional ball mill: 750 kW; and Tower Mill: 520 kW (Young et al, 1997; Young, Pease and Fisher, 2000). From an energetic point of view only, the older configuration consumed less than half of
today’s energy. The feed rate is not mentioned in either case. Recently, Olson and Dixon (2009) have installed a vertical stirred mill prior to the ISA mill at Goldcorp Peñasquito to grind from 125 μm to 30 μm.

**DISCUSSION**

When larger grinding balls are ejected from a ball mill, it is caused by the operating conditions. So does the small media. Their ejection can be overcome. The first and main cause remains the pulp density. As mentioned by Klein and Hallbom (2009), as the particle size in slurry gets finer and solids concentration increases, the non-Newtonian effects become more pronounced. For the moment, diluting the pulp is one solution. Viscosity modifiers can be a second alternative. When adding more water, the flow rate is increased. As stated by McIvor (2009), every extra unit of water can lead to significant improvement in the circuit classification system efficiency, over grinding and energy efficiency. So far, small media has stayed in ball mills for slurry linear velocity less than 3.3 m/min. Studies should be conducted to better understand the rheology effect of both concentration and flow on media sizing.

Feed size dictates media sizing. Bond top size ball formula gives a good indication if the mill needs smaller media as shown in Table 3. When finer grinding is not needed, significant energy improvement can be achieved. Unfortunately, that formula cannot be used in vertical stirred mills, which accepts balls size up to 30 mm. Stirred pilot mill can now be related to industrial performance by using the same size of small grinding media. More studies are needed to correlate feed size to top media sizing. It is also important to mention that in all those industrial cases, no circuit optimisation was conducted.

**CONCLUSIONS**

To use small media into industrial mills, two identified operating criteria must be met. The most important factor is the pulp’s density which must be fluid enough. The second is the media volume must be kept below the trunnion level. The power target need to be lowered when converting a mill charge. Flow rate is important but the critical value still need to be found. For energy improvement, the maximal feed size range to use small media like Millpebs (5 - 12mm) is 250 μm. Therefore, both fine grinding and regrind applications required media size smaller than 12 mm.

The first benefit of using small media is energy savings. Compared to 25 mm media, small media reduces the energy consumption by 36 per cent to 40 per cent in ball mills and 33 per cent in vertical stirred mill. A vertical stirred mill reduces further the energy by 43 per cent versus a ball mill. The combination of small media in a vertical stirred mill requires at least 60 per cent less power than conventional ball mill using 25 mm balls. More savings were identified.

For a feed size greater than 100 μm, small media in a regrind ball mill showed a better energy efficiency than the Isa Mill based on the Operating Work Index (16.7 versus 54.7 kWh/t). None of those trials were final and optimised. Further investigation is needed. To grind from a feed size of 37 μm down to 12 μm, the use of a ball mill and vertical mill combination was requiring less power than the Isa Mills and vertical mill combination.

Finally, both technology and media size are important. A vertical stirred mill with small media represents the best potential to decrease the energy consumption in the fine grinding and regrind application. The Isa Mill might not be as energy efficient due to very small grinding media. The limit between the fine and ultra fine grinding should be found as they required different size of grinding media (1 - 3 mm versus 5 - 12 mm). The operation of vertical stirred mill needs further investigation through process optimisation, which should results in both lower energy and media consumption. The sizing of this equipment with small media will become more important in the future.

**ACKNOWLEDGEMENTS**

The author wishes to thank all the concerned mining companies and all the personnel who collaborated for their support during those industrial trials, especially Curtis Deredin and Mark Furlotte from Brunswick Mining, Claude Bazin from Laval University and Serge Parent from Wheelabrator Allevard.
REFERENCES


