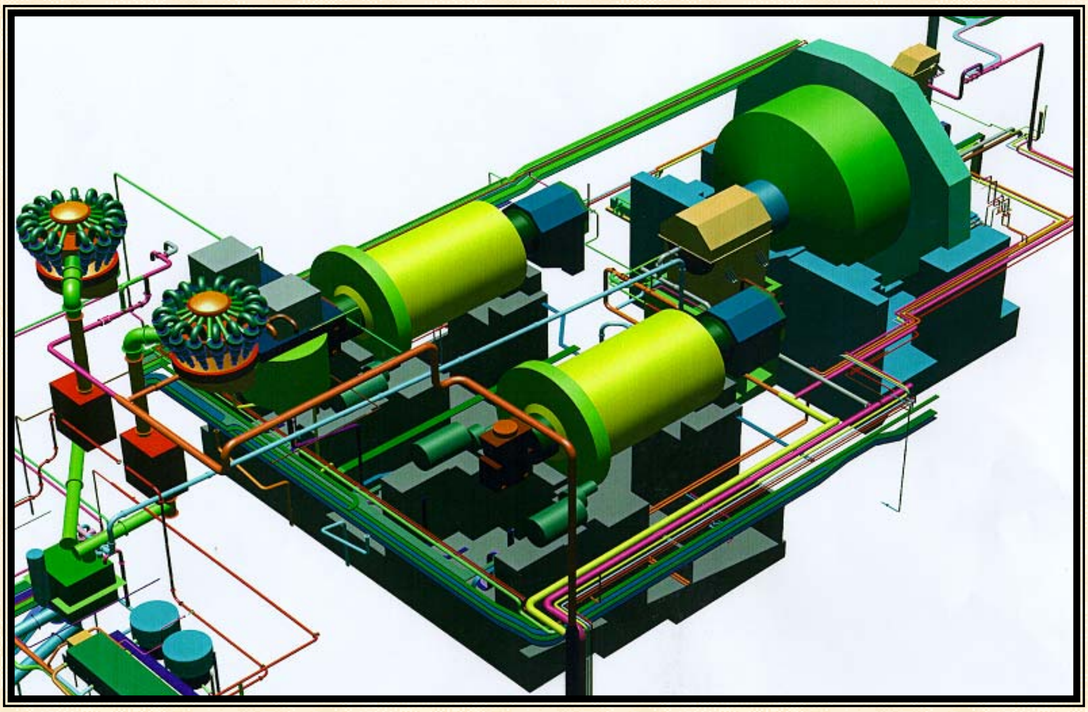

Selection of Comminution Circuits for Improved Efficiency

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Abstract

This paper examines the design of comminution circuits and the issues that impact on comminution circuit efficiency.

Circuit efficiency is discussed, principally from the perspective of power efficiency. However, operating efficiency, maintenance efficiency, capital expenditure and return on investment are often the key efficiency factors in project development outweighing power efficiency considerations.

Comminution circuits have progressed from circuits comprising simple crushing machines, for example stamp batteries, through multi-stage crushing and staged grinding, to single stage crushing and semi-autogenous grinding (SAG) and ball mill (SAB) circuits. This progression has, not necessarily, been accompanied by an improvement in the efficiency of power utilisation in achieving the target grind size, but has seen an improvement in the overall efficiency of mineral processing as measured by the overall cost of grinding to the required size for effective downstream beneficiation of the value metal or mineral.

In the future, projects that add value by improving power efficiency and reducing CO_2-equivalent output may earn Emission Reduction Units (ERU's). The value of an ERU is hard to predict and the achievable reduction will be a function of comminution technology and site specific factors such as the method of power production.

WHAT IS GRINDING EFFICIENCY?

Technically, grinding circuit efficiency refers to the amount of energy used to grind from a certain feed size to a product size as measured against a benchmark, such as that determined by Bond formulae adapted by Rowland (Rowland 1982).

From a business perspective, efficiency may be measured according to the cost per unit of the grinding circuit product. That cost is comprised of the following components:

- cost of capital
- labour;
- maintenance materials;
- power, and
- consumables.

The relative importance of each of these components will vary depending upon the ore characteristics, plant location, circuit selection and plant capacity.

Impact of Circuit Capacity

In general, optimising fixed costs, such as labour costs, is most leveraging for low tonnage plants whilst optimising variable costs, such as energy consumption and media costs is most leveraging for high tonnage plants.

Consider two cases, a modest flotation-based operation at 1 Mt/a and a large tonnage operation of 20 Mt/a. Table 1 summarises the operating costs for these plants. Obviously the location and type of plant impacts significantly on operating costs. For instance, the Cadia Hill plant operating costs are approximately $3.60 /t due to the coarse grind size, simple plant and low power cost. Conversely, a 1 Mt base metals flotation plant in Tasmania had operating costs of $16/t due to the fine grind size and complex flotation circuit.

The distribution of costs between the cost centres for the two plants is very different. For a modest plant, nearly 50% of costs are labour related, 17% of costs are for comminution power. For the large plant, less than 10% of costs are labour related and 28% of costs are for comminution power.

Table 1 SUMMARY OF PLANT OPERATING COSTS				
Area	**1 Mt/a Plant**		**20 Mt/a Plant**	
		Cost $/t		**Cost $/t**
Personnel				
- number (including maintenance)	60		120	
- cost with on-costs	$6 M/a	6.00	$ 12 M/a	0.60
Power				
- power cost, $/kWh	$0.12/kWh		$0.08/kWh	
- comminution circuit, kWh/t	18 kWh/t	2.16	18 kWh/t	1.64
- other plant, kWh/t	12 kWh/t	1.44	12 kWh/t	0.96
Maintenance Materials				
- comminution circuit	$0.70M /a	0.55	$9 M/a	0.45
- other plant	$0.55M /a	0.55	$4 M/a	0.20
Consumables				
- grinding media	$1M /a	1.00	$20 M/a	1.00
- reagents and general consumables	$1M /a	1.00	$20 M/a	1.00
TOTAL		**12.70**		**5.85**

A 1 Mt/a plant may have a capital cost of between $25 000 /t/h and $50 000 /t/h compared with between $10 000 /t/h and $20 000 /t/h for a 20 Mt/a plant, dependent on complexity. Approximately $9M and $120M is expended on the comminution circuit (crushing, stockpiling and grinding) representing 35% and 50% of plant capital cost for the 1 Mt/a and 20 Mt/a plants, respectively.

Comminution costs include power, grinding media and maintenance materials. These costs represent 30% of costs for the 1 Mt/a plant and over 50% of costs for the 20 Mt/a plant.

Thus, the "efficiency" of a modest plant is improved by simplifying the comminution circuit and reducing labour requirements. Improving the grinding efficiency of the comminution circuit by 10% will improve plant operating costs by less than 3%.

The "efficiency" of a large plant is not greatly impacted by the labour costs (within sensible limits). A 10% improvement in comminution circuit grinding efficiency leads to a 5% improvement in plant costs.

Impact of Circuit Type

Comminution circuits in mineral processing plants is Australasia fall into the following categories:

- single stage crush and single stage grind with steel media, eg Cosmos Nickel Mine (Fleay et al 2000).
- single stage crush and single stage autogenous grind, e.g. Kambalda Nickel Mines (Esvelt, 1997), Olympic Dam, post 1995.
- single stage crush, SAB, e.g. Macraes Gold Mine.

- single stage crush, SABC, e.g. Cadia Hill Copper/Gold Mine (Dunne et al 2001, Hart et al 2001).
- single stage crush, ABC, e.g. Ridgeway Mine (gold/copper), Olympic Dam, 1986-1995.
- single stage crush, rock and pebble mill as operated at Mt Edon Gold Mine and Forrestania Nickel Mines[1] (Rantanen et al, 1996).
- three stage crush, rod and ball mill, e.g. Renison Bell Tin Mine.
- three stage crush, two stage ball mill, e.g. Marvel Loch Gold Mine.
- two stage crush, two stage ball mill, e.g. Bronzewing Gold Mine (Lane et al, 1997).
- three stage crush, ball mill e.g. (Three Mile Hill).
- two stage crush, ball mill, e.g. Pajingo.
- a crushing circuit including high pressure grinding rolls (HPGR) at Argyle Diamond Mine.

Recent feasibility studies for the Boddington Expansion Project have considered the use of HPGR for hard rock multi-stage crushing and ball mill circuits at high tonnage rates (Parker et al, 2001).

Table 2 provides a simple comparison of the various comminution circuits. The primary mill may be operated in open circuit or closed by a classifier, such as a screen or a hydrocyclone. Closing the primary mill may result in an improvement in operating efficiency for some operations, or may facilitate a reduction in the primary mill product size.

[1] Plant relocated to Black Swan

Table 2

SUMMARY OF COMMINUTION CIRCUITS

	Steel Media Circuits						**Semi-autogenous Circuits**				**Autogenous Circuits**	
Crushing	two stage crush	three stage crush	crushing circuit including high pressure grinding rolls	three stage crush, rod and ball mill,	three stage crush	two stage crush	single stage crush	single stage crush	single or two stage stage crush	single stage crush	single stage crush	single stage crush
Primary Milling	ball mill	ball mill	ball mill	rod mill	ball mill	ball mill	single stage SAG mill	SAG mill	SAG mill and pebble crush	AG mill and pebble crush	single stage autogenous grind	rock mill (with pebble crush)
Secondary Milling				ball mill	ball mill	ball mill		ball mill	ball mill	ball mill		pebble mill
Examples in Australia	Pajingo, Karonie	Harbour Lights	Proposed for Boddington	Renison, Luina	Marvel Loch (post 2001)	Marvel Loch (pre 2001)	Cosmos	Macraes	Cadia, North Parkes, Fimiston	Ridgeway, Scuddles, Olympic Dam	Kambalda and Olympic Dam (upgrades)	Kambalda, Forrestania Mt Edon Black Swan
Power Efficiency [2]	1.05	1.0	0.95 – 1.0	1.0	1.0	1.0-1.05	1.3 – 1.7	1.3 – 1.5	1.25 – 1.4	1.25 - 1.5	1.1 to 1.4	1.25 – 1.5
Power Efficiency [3]	1.0	1.0	0.95 – 1.0	1.0	1.0	1.0	1.0 - 1.25	1.0 - 1.2	1.0 – 1.25	1.0 – 1.15	0.9 – 1.0	0.9 – 1.1
Media Consumption	1.1	1.0	1.0	1.3	1.0	1.1	1.1	1.1	1.1	0.6	0	0
Maintenance Requirement	moderate	mod. to high	TBA	high	high	high	low	moderate	mod - high	mod - high	low	moderate
Operability / Issues	High reduction ration in crushing	More complex crushing and screening	Lack of experience in hard ore mineral applications	Rod addition an issue, narrow rod mill product size dist	Higher maintenance with grate d/c mill	Higher maintenance with grate d/c mill	Variation in ore competency an issue	Current benchmark	Pebble crushing impacts on SAG mill operation	AG/PC circuits require good control systems	Suitable	Pebble management an issue. Requires complex circuit
Applicability	Low throughput <100 t/h	Suitable for moderate capacity circuits	Alternative to SABC for high throughput and competent ore	Yields narrow rod mill product size dist	Suitable for moderate capacity circuits	Suitable for moderate capacity circuits	Low to moderate throughput. Low to moderate competency feed	OK for moderate competency ore	OK for moderate to high competency ore	Suitable for moderate competency ores	Some indications of high power efficiency with some ore types	Homogenous moderate competency well defined ore bodies

[2] milling competent ore (e.g BWI 13 kWh/t, RWI 20 kWh/t)
[3] milling non competent ore (e.g BWI 13 kWh/t, RWI 13 kWh/t)

THE IDEAL CIRCUIT ?

The benchmark circuit varies with plant capacity and ore competency:

- Single stage crush/single stage SAG mills and two stage crush/ball mill circuits are typically selected for low throughput plants (<50 t/h) where personnel costs are a large component of costs.
- SAB circuits are typically selected for plants of 0.5 to 2 Mt/a.
- SABC circuits are typically selected for plants above 2 Mt/a treating moderate to high competency ores.
- Single stage autogenous circuits have been considered for chlorite, iron ore and serpentine based ores and have proven energy efficient at pilot and plant scale.
- HPGRs are being considered for large (>15 Mt/a) plants treating competent ores to simplify the crushing circuit and improve power efficiency. The cost of HPGRs biases there effective use to large tonnage circuits, with 60 t/h units costing approximately $2M and 2000 t/h units costing just over $10M.

Table 3 illustrates how circuit selection may be affected by plant capacity and ore competency.

Table 3

MATRIX OF COMPETENCY AND CAPACITY – EXAMPLES ONLY

Competency	**Grinding Circuit Throughput**			
	< 0.5 Mt/a	**0.5 to 2 Mt/a**	**2 to 6 Mt/a**	**> 6 Mt/a**
Low	Single stage SAG	Single stage SAG	Single stage SAG	SAB
Moderate	Single stage AG	Single stage AG, SAB & ABC	Single stage AG, SAB & ABC	ABC
High	Two stage crush/ball mill	Stage crush/ball mill & SABC	SABC	SABC & Stage crush/HPGR/ ball mill

The ideal circuit is easy to operate and maintain, is power efficient and has a low or no steel media consumption. In addition, the size distribution and grinding circuit chemistry may impact on the performance of the downstream circuit (Lane, 1999 and Rantanen, 1996).

Fully autogenous circuits are attractive due to the elimination of steel media costs. Typically, a SAG mill based circuit (P80 of 106 to 150 um) has media costs of around A$1/t. Providing the ore is amenable, the use of primary autogenous milling can reduce this cost by 40%. Autogenous milling is typically practiced in association with pebble crushing to improve circuit power efficiency. The pebble flow provides an ideal source of media for secondary milling and a number of circuits have been developed such as those formerly operated by Outokumpu at Forrestania (Koivistoinen and Virtinan, 1996).

The power efficiency of a fully autogenous milling circuit is potentially better than that of a SAB circuit provided that ore competency is not excessive, the primary mill screen-cut is relatively fine (2 mm) and the secondary mill media is selected appropriately (a range of 10 to 70 mm for a 2 mm aperture SAG mill discharge screen). Some circuits have operated with relatively coarse transfer sizes to the secondary mill, requiring secondary media as coarse as 120 mm and resulting in reduced milling efficiency.

Fully autogenous circuits were becoming increasingly common in the 1960's. Autogenous grinding (AG) as the primary stage of grinding remains an accepted approach. However, AG milling requires more testwork to define the ore competency characteristics though an orebody, and comes at a higher capital cost when compared with a comparable capacity semi-autogenous grinding (SAG) circuit. The capital cost differential is reduced where the ore specific gravity is high, for example in iron ore milling at Empire in Canada and Olympic Dam in Australia.

Experience With Fully Autogenous Circuits

If fully autogenous milling is power efficient and has no requirement for steel media, why isn't it used everywhere? Surely this would be the case if it was perceived to be "efficient".

Single stage autogenous milling has proven effective for a number of ore types. The success of this approach is reliant on maintaining an effective rock media charge. Thus, the ore has to be sufficiently competent to establish a charge and not so competent or lacking in lumps that the media charge becomes critical, with the result that the mill product size becomes too fine, grossly decreasing circuit efficiency.

Work conducted at pilot scale for the Kambalda installation (Esvelt, 1997) indicated a strong relationship between circuit efficiency and rock charge size distribution. Over crushing of the pebble stream led to extreme circulating loads about the cyclone (>2000% at pilot scale) due to the lack of suitable media in the grinding charge.

Regulated pebble crushing can be used to control the rock charge build-up, as at Savage River (ABC circuit), where the pebble crusher is brought in circuit as the mill load builds up, and taken off-line as the load decreases. When the Olympic Dam grinding circuit was upgraded in 1995, an operating cost saving of $0.95/t was realised in converting from an ABC to a single stage autogenous circuit. This included a reduction in mill specific power from 20.8 kWh/t for the ABC circuit to 19.1 kWh/t for the single stage autogenous circuit. An interesting comparison of the effect of pebble crushing in single stage AG milling has been observed at Olympic Dam. Equipment in use comprises a 10.36 m (34-ft) diameter AG mill, which operates in closed circuit with a recycle crusher and cyclones, and an 11.6 m (38- ft) diameter mill, which operated in circuit with cyclones but no recycle crusher. Typically, the 34-ft mill is using 1 to 2 kWh/t less than the 38-ft mill on similar feeds, and this difference is attributed to charge size control flowing from the recycle crusher. If the feed size distribution is not optimum (too much mid size), pebble crushing allows limited ability to improve performance.

The issues associated with the implementation and operation of fully autogenous circuits have been documented on many occasions. A few examples are cited below:

- The principal disadvantages of fully autogenous circuits are the requirements to
  - undertake pilot plant testwork;
  - expend additional capital for large mill shells and pebble handling systems;
  - understand the breakage characteristics of the orebody, particularly with regard to variability, and
  - operation is highly dependent on the feed size emanating from the stockpile/reclaim system.

- The key to successful autogenous milling, in particular, is correct feed preparation. Nothing is more important than preserving a consistent blend containing adequate lump media. Without this, steady operation becomes difficult to achieve.

- To offset the risk of ore variability, developers tend to provide contingency by designing the mills to take high steel media loads, and providing very high quality stockpiling and retrieval arrangements. This adds to the already higher capital cost.

- Zinkgruvan Pb/Zn mine in Sweden experienced problems with critical size build up in the single stage AG mill. This was overcome by controlling the feed size distribution to the mill through secondary crushing the critical size distribution and screening the feed and separate stockpiling, with a resultant reduction in power consumption from 24 kWh/t to 15 kWh/t (Mellberg et al, 1996) .

- Similarly, Kambalda's single stage AG mill controls the critical size by moderating the primary crusher product size and crushing critical size pebbles as required (Esvelt, 1997). The mill tends to produce a finer product than is optimum for the subsequent recovery of nickel sulfides.

- A number of fully autogenous circuits have been converted to steel media circuits due to poor control, poor power efficiency or requirements to increase throughput. Typical of these is Tarmoola. (Kar, 1999). There are many reports of the difficulties associated with pebble milling with blocked grates, pebble handling issues and poor control (Rovig, 1975).

- Many autogenous circuits are converted to semi-autogenous or ball mill grinding circuits over time to increase throughput.

- ROM autogenous milling has been practiced in South Africa for many years. The ROM mills operate at higher mill filling (>40%) and higher speeds (90% of critical) than typical North American or Australian autogenous mills. Operation in this mode with competent feeds may lead to very high energy consumption, high fines production and relatively inefficient operation. However, with moderate competency ore, the efficiencies are akin to those experienced in Australian single stage autogenous mills.

What Happened to Pebble Milling?

In 1959, Rio Tinto's Elliot Lake circuit was converted from ball milling to pebble milling to reduce reagent consumption in subsequent uranium leaching (Roach, 1963). Problems were reported with blinding of grates, liner wear, screening and pebble handling. The power consumption in pebble milling was reported to be between 5 and 10% higher than the previous ball mill circuit, but was offset by substantial media (1 kg/t tonne) and reagent cost. Pebbles for the pebble mill were obtained by screening in the crushing circuit. Similar circuits were installed in sulfide milling circuits, such as the Kambalda Nickel Operations rock/pebble mill circuit operated in the early 1970s.

A review of pebble milling practice was reported in 1972 (Oyasaeter, 1972) proclaiming "world wide acceptance" of pebble milling. However, with the exception of Scandinavian sulfide plants and North American iron ore operations very few plants have been designed and operated using pebble milling technology. Interestingly, one of the conclusions of that review was that pebble consumption increases with pebble mill diameter for low to moderate competency ore (mostly sulfide and iron ore applications). Pebbles were typically sourced from a screened fraction from the crushing plant or from the porting of the primary mill.

Extensive pilot plant trials conducted for the Nkomati project (Bradford et al, 1998) as summarised in Table 4 (BWI 17 to 26 kWh/t). SAG and AG mill trails were conducted using high charge levels (typical of South African practice) and direct comparison with typical Australian SABC circuit power efficiency is difficult. However, the high BWI and reported competency characteristics indicate that a circuit specific power of 20 to 22 kWh/t is likely.

The trends in the data for Nkomati are typical of most pilot trials on ore of moderate competency and high hardness. Pilot trials on high competency ores show a far higher differential in specific power between single stage autogenous and circuits containing pebble crushers due to the build-up in critical size in the mill load.

Table 4

SUMMARY OF NKOMATI PILOT PLANT DATA (FROM BRADFORD ET AL, 1998)

	Single Stage Autogenous	Single Stage Autogenous and Pebble Crusher	Single Stage SAG	AG / Pebble Crush/ Pebble Mill
Product Size (µm)	76	72	73	76
Specific power (kWh/t)	24.8	20.6	22.9	21.9
Cyclone Circulating Load %	273%	655%	441%	128%

The Forrestania plant operated by Outokumpu, now at Black Swan and operated by MPI, is the best documented and arguably most successful two stage fully autogenous circuit in Australia. Both Forrestania and WMC's Kambalda Nickel Operations (single stage autogenous) benefit from improved downstream metallurgy as a result improved pyrrhotite depression.

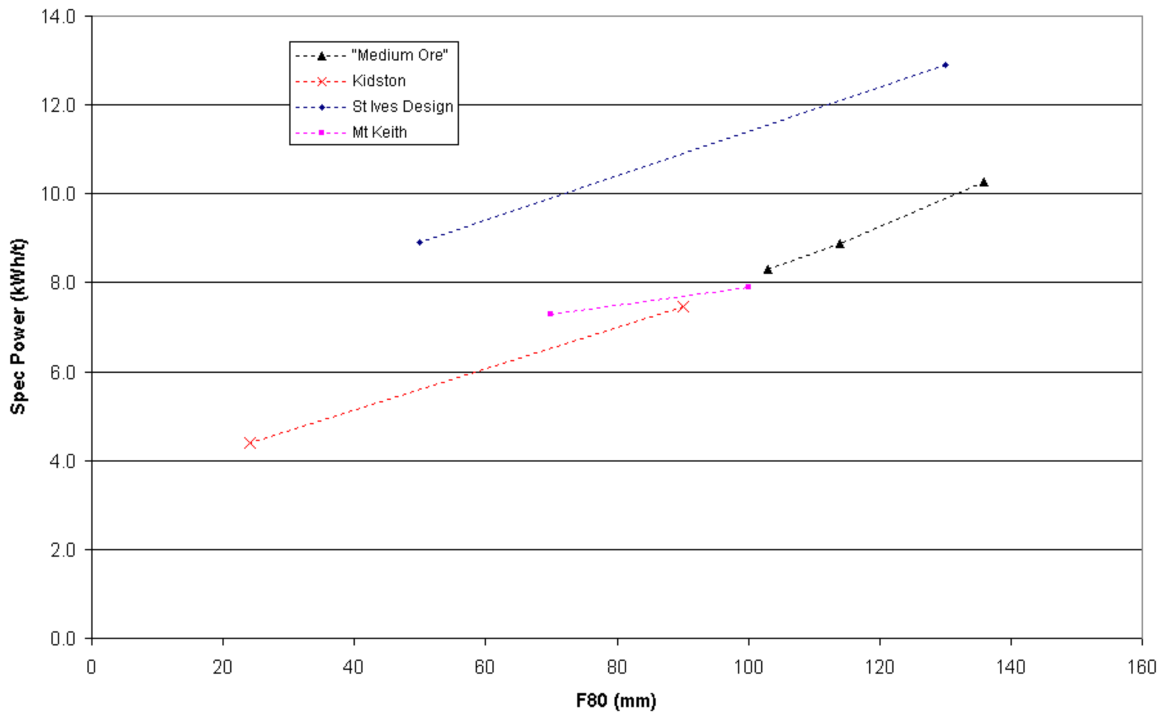
Numerous pilot plant trials have been conducted by Outokumpu on Forrestania and other ores that indicates the Outokumpu "Outogenious" approach to milling is at least comparable in power efficiency to rod/ball milling (Koivistoinen et al 1996).

Impact of AG and SAG Mill Feed Size on Grinding Power Efficiency

AG and SAG mills are sensitive to feed size distribution. AG mills suffer if there is an absence of "lump" material that may be used as media, resulting in a reduction in "impact breakage" and lower mill throughput. For SAG mills, where the media is supplied to the mill as steel balls, the finer the feed the higher the unit capacity. High unit capacity does not always mean high circuit efficiency as the product size distribution is coarser at high mill throughput increasing the load on the subsequent ball mill. In large capacity SABC circuits operating at high SAG mill ball load, ball mill capacity is often a limiting factor.

Figure 1

IMPACT OF FEED SIZE ON SAG MILL SPECIFIC POWER FOR ORES OF MODERATE TO HIGH COMPETENCY



To counter high ore competency, the ball to rock ratio can be increased and/or the ball size increased. However, at best, an inefficient SAG milling operation is obtained with a power demand typically 30% more than theoretical Bond power for the same size reduction.

Kidston Gold Mine (MacNevin, 1997) benefited from the increased SAG mill capacity resulting from a finer SAG mill feed although the SAG mill operating work index was unaffected (Lane and Siddall, 2002).

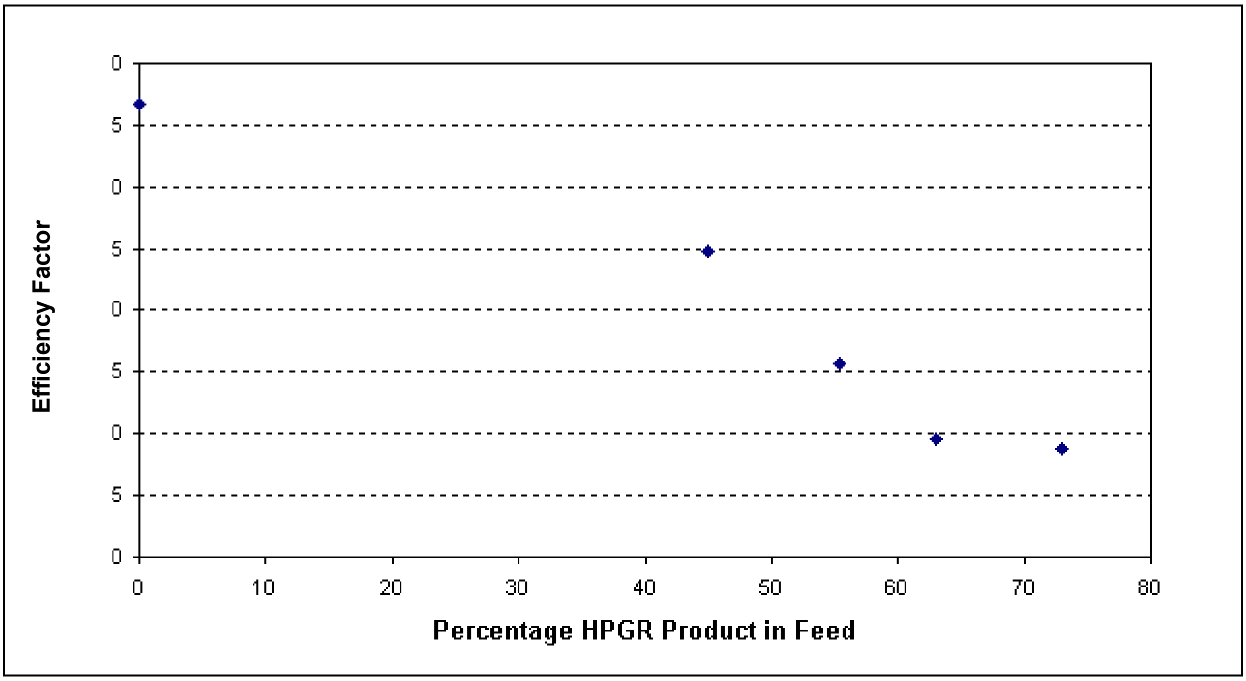
Data from St Ives (Atasoy et al 2001) indicated that a decrease in the 80% passing size from 102 mm to 21 mm resulted in a change in circuit operating work index from 27.1 kWh/t to 21.8 kWh/t. The operating work index of the SAG mill actually increased with fine feed. The ball mill operating index for the coarse feed case was very high considering the fine product size from the SAG mill indicating a high low reduction ratio inefficiency factor and/or inefficiency in hydrocyclone classification circuit.

KCGM have been reconsidering partial secondary crushing (25%) of SAG feed due to voids in pit and poor blast fragmentation (Karageorgos, 2001). WMC are currently testing partial secondary crushing in a full scale 3 month plant trial at Mt Keith.

Secondary crushing of SAG mill feed has also been used by plant designers to minimise the capital cost of gold projects by allowing single stage milling where the ore varies from initial oxide to competent rock over the mine life. The secondary crushing of the competent primary ore allows the same mill to be used, as the ore competency increases (within limits). For these projects the broadness of the product size distribution is not critical in downstream leaching. Examples are Jundee and Bronzewing (Lane and Lunt, 1997).

The impact of High Pressure Grinding Rolls (HPGR) crushing of a screened primary crushed stream[4] and feeding a blend of primary crushed and HPGR product to the SAG mill has been tested at pilot scale for Boddington diorite ore. The SABC power efficiency was significantly improved as the feed size decreased, as illustrated in Figure 2 (Rowe, 2001).

Figure 2
RELATIONSHIP BETWEEN %HPGR IN FEED AND SABC GRINDING CIRCUIT EFFICIENCY



[4] HPGR fed by –55 mm material

Impact of Closed Circuit Milling

Operation of a SAG or AG mill in closed circuit with screens or hydrocyclone has been considered more energy efficient with the recycle stream benefiting from some degree of “free milling”.

Recent pilot plant trials on ore for the Mt Keith expansion studies concluded that there was no statistical difference in overall circuit efficiency between closed circuit and open circuit SAG milling in an SAB circuit (Table 5).

Table 5

MT KEITH PILOT PLANT TRIAL EFFICIENCY FACTORS FOR VARIOUS CIRCUIT CONFIGURATIONS

Circuit Type	Open or Closed SAG Mill[5]	Circuit F80 (mm)	Efficiency Factor
SAB	closed	83	0.90
SAB	closed	99	0.95
SAB	open	106	0.91
SAB	open	99	0.85
SAB	open	69	0.85
SAB	open	92	0.84
SABC	open	99	0.86
SABC	open	98	0.93

The issue of slurry pooling and the importance of effective pulp lifter design for closed circuit mills is now better defined leading to improvements in closed circuit AG and SAG mill performance.

Impact of Circulating Steel on Power Efficiency

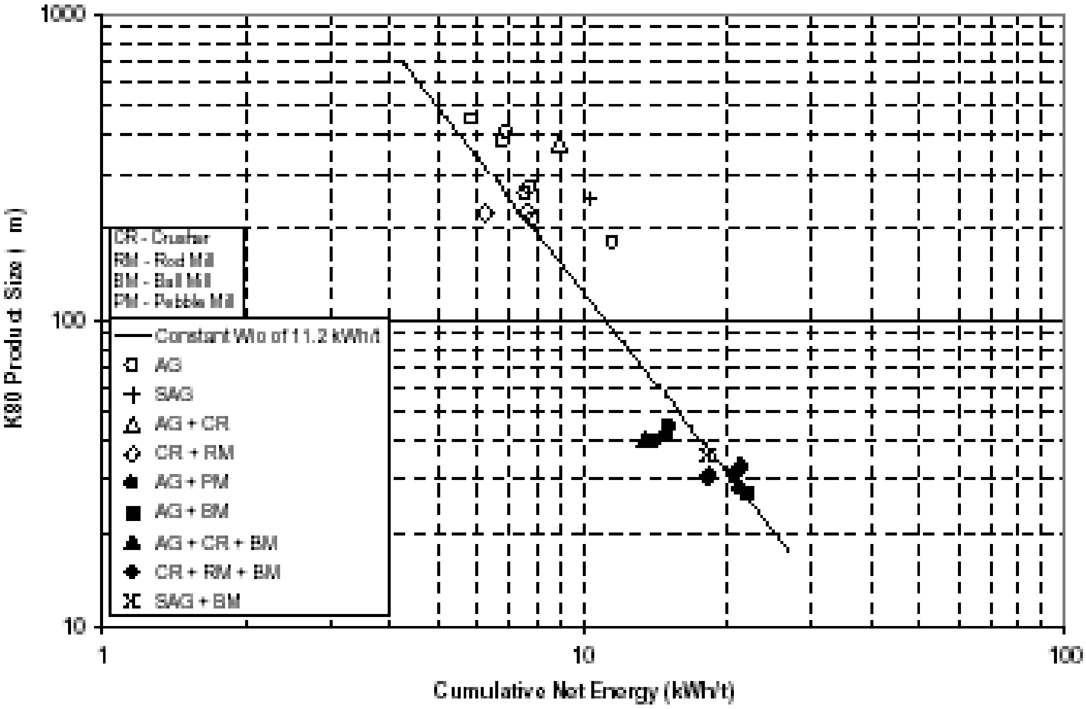
The impact on milling efficiency of removing ball scats from a single stage mill has been reported to be significant at Navachab (Powell, 2001). The removal of ball chips allowed a 10% increase (possibly due to decreased pebble crusher bypass) in throughput with a 2% increase in –75 µm production. Efficiency improvements have been reported by Ereiz Magnetics at Escondida and Los Pelambres (Shuttleworth et al, 2001). The reduction in pump wear is the principal benefit in removing the small ball chips from the circulating load.

[5] With 2 mm screen

Low/Moderate Competency Ore

A rod/ball mill circuit was replaced by a SAB circuit at the Brunswick concentrator. The Pb/Zn ore is typically massive sulfide and of relatively low competency compared with Australia hard rock deposits and is ground to P80 of 40 µm. The power consumptions and efficiencies of the SAB and rod/ball mill circuits were comparable, but steel consumption dropped from 2 kg/t for the rod/ball mill circuit to 1 kg/t for the SAB circuit (Larsen, 2001), as shown in Figure 3.

Figure 3
COMPARISON OF MILLING EFFICEINCY AT PILOT SCALE FOR BRUNSWICK ORE
(FROM LARSEN, 2001)



The Use of HPGR in Stage Crushing and Ball Mill Circuits

HPGR may be used as a substitute for the tertiary cone crushing in stage crushing/ball mill circuits. The advantages include the high unit capacity, high reduction ratio and possible power efficiency benefits in subsequent grinding.

Figure 2 indicates that an SABC circuit operating on Boddington diorite ore was expected to consume over 1.35 times the power predicted by Bond formulae due to the high ore competency. Secondary crushing and partial HPGR of SAG mill feed improved power efficiency. However, three stage crushing with the last stage using HPGR followed by single stage ball milling is expected to result in a comminution circuit that uses between 95% and 100% of Bond predicted power. This represents approximately a $0.60/t saving in operating costs (based on the example in Table 1).

HPGR present a significant opportunity if the high capacity HPGR units can be operated and maintained at a lower cost than multiple short head cone crushers. The acceptance of HPGR in main stream mineral processing of competent ores relies entirely on maintenance and wear efficiencies and associated costs. Presently the risks associated with HPGR are considered by many to be greater than the possible benefits.

EMISSION REDUCTION UNITS

Emission reduction units (Reuse) are a reflection of the energy efficiency of the process and may become a significant consideration in the approval of future projects (possibly within the next 10 years). For comminution, the major contributors are grinding power and steel media consumption. Reuse are calculated based on the reduction in CO_2-equivalent generated in producing power and steel media.

The actual quantum of the ERU might be measured in a number of ways. The most likely situation could be 'cap and trade' i.e. the legislating body sets the bar for a new project and if you are above or below it you trade accordingly. The other possibility is to establish a baseline for the particular industry / processing route. This is relatively easy for industries such as waste treatment, where the baseline is landfill, but more difficult to establish for mineral processing where the flowsheets are diverse. The annual saving in power and media is converted to the equivalent tonnes of CO_2 that have been emitted in raising the power and producing the steel media.

The number will vary state to state in Australia. For example, power produced in Tasmania would have a low value because hydroelectricity is the main power source. Emissions will be more significant with thermal generated power with bench levels ranging from 1,22 tCO_2e/MWh for brown coal, through 0.86 tCO_2e/MWh for black coal, 0.68 tCO_2e/MWh for diesel power, to 0.53 tCO_2e/MWh for a natural gas fired gas turbine (AGO, 2000)

Emission reductions from reduced steel consumption will depend on steel production technology and transport distance. An indicative value for steel from an integrated plant would be 1.6 tCO_2e/t steel (IPCC, 1996). Future trading in ERUs could impact on the selection of comminution circuits, while carbon taxes may help fuel the drive to greater efficiency. For the examples given in Table 1 a carbon tax at \$10 /tCO_2e would increase operating cost of the 1 Mt/a plant with diesel power by almost 2% and for the 20 Mt/a plant with natural gas power by almost 3%. As ERUs are a function of the political climate and world response to environmental issues, it is difficult to judge the pertinence of ERUs to plant design in the coming years. However, the above discussion serves to illustrate some of the issues that may contribute to a changing measure of “efficiency” and increased reliance on energy efficiency as a key factor in design.

CONCLUSION

The SAB and SABC circuits that are the benchmark of current comminution practice are not the most energy efficient option, nor are they the lowest steel media consuming option available to the developers of projects milling competent ores. However, the efficiencies associated with ease and robustness of operation often exceed the potential operating savings of autogenous circuits. The lower maintenance costs and reduced number of operating units advantage semi-autogenous and autogenous circuits when compared with the conventional stage crush and staged grinding circuits.

The effort required in the project development phase to implement autogenous grinding circuits or HPGR in a crushing circuit is much greater. Autogenous milling benefits from a high degree of orebody characterisation and a relatively homogenous orebody. HPGR performance characterisation requires additional testwork at benchscale to that conducted for a SAG/AG mill circuit. Thus, the decision to consider HPGR needs to be made early in the metallurgical characterisation program.

Where ore characteristics have been appropriate, autogenous grinding circuits have proven to be robust, operable and more efficient circuits with savings in both power and media costs. The potential efficiency gains can “make or break” moderate to large tonnage, low margin operations.

The possible introduction of ERUs due to environmental factors may change the decision process for the selection of a comminution circuit and autogenous circuits may re-emerge.

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GLOSSARY OF ABBREVIATIONS

AG – Autogenous Grinding
SAG – Semi-Autogenous Grinding
kW - Kilowatt
MW -Megawatt
SABC – SAG Mill/Ball Mill/Crusher
ABC – AG Mill/Ball Mill/Crusher
HPGR – High Pressure Grinding Rolls
PM – Pebble Mill